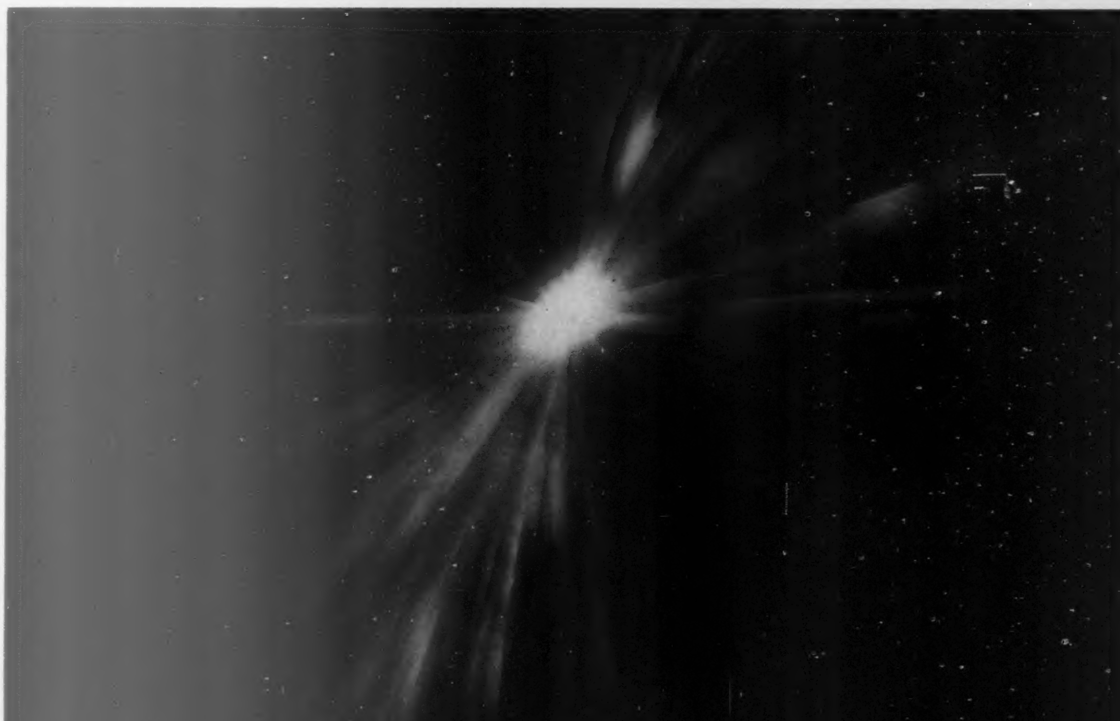
ALLIS-CHALMERS

Electrical Review



September 1945

Why "Regulex" is No. 1 Arc Furnace Control

LOWER MELTING COSTS, REPORTED BY SCORES OF ELECTRIC FURNACE OPERATORS WHO USE RUGGED REGULEX ELECTRODE CONTROL, HELP EXPLAIN ITS RAPID RISE TO TOP POPULARITY

TODAY, Regulex control is acclaimed as *the most popular of any modern arc furnace control.* By its low maintenance and superior performance, it has outmoded conventional, slow-acting controls of the contactor type.

The Regulex control consists of a very simple, continuously-connected system of generators and motors.

Regulex generators, one for each electrode motor, are driven on a common shaft from a standard induction motor.

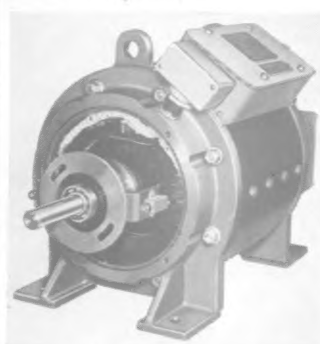
Balanced Control Circuit

The Regulex system is able to adjust itself to any demand, no matter how small or how large — an important characteristic in an arc furnace control.

Furnace Using Regulex Control

When the balance of voltage and current in the furnace arcs is upset, the control fields of the Regulex generators become correspondingly unbalanced. Instantly, the control supplies an amplified voltage to the electrode motors, causing them to raise or lower the electrodes, correcting the power unbalance.

Continuous, smooth, and stepless regulation results. No mechanical brakes are needed.



Sturdy Regulex Generator

By accurately controlling electrode position during all the changing conditions of the furnace charge, Regulex control lowers kilowatt-hour cost per ton of steel, because wasteful current peaks are ironed out. Melt-down time is shortened . . . furnace production is boosted!

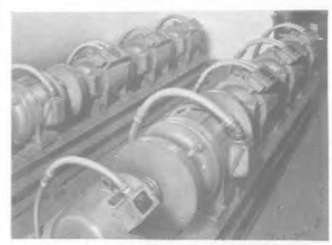
Standard Machine

The Regulex generator is a sturdy, standard commutator machine, *which requires no tricky brush adjustments.*

Springs, levers, contactors, etc., are replaced in the control scheme by the Regulex generator, which has *only its armature* as a moving part. Maintenance is slashed!

Unique Advantages

As an exclusive feature, Regulex control can be equipped with flywheels, which automatically raise



Regulex Control Flywheel Sets

the electrodes when power fails. The auxiliary generator can make the entire control independent of a d-c shop source when desired.

Pays for Itself

Varied field experience has proved that in time and power savings, *not counting maintenance economy,* Regulex control often pays for itself within a few months. Kilowatthour consumption on furnaces equipped with Regulex control *may be cut as much as 10%,* in comparison with power costs on furnaces equipped with older-type controls.

Ask Furnace Manufacturer

Your arc furnace manufacturer will be glad to tell you about Regulex control for new or existing furnaces. Or write directly to ALLIS-CHALMERS, MILWAUKEE 1, WIS.

ALLIS-CHALMERS · MILWAUKEE

A 1887

REFLECTED IMAGES in the plane's window and atmospheric refraction combined to give a fireworks effect to this aerial glimpse (cover) of the sun's eclipse by the moon on July 9th. An overcast sky forced observers to 10,000 feet, with ice forming on plane wings, before breaking through clouds just three minutes before the eclipse. How the eclipse affects electrical power transmission equipment is revealed on pages 4 to 11.

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Eclipse Reveals Solar Secrets *about Atmospheric Electricity*

ECLIPSE observers record significant change in potential gradient of the earth's atmosphere, probably resulting from the moon's shadow, which may have significant effect on electric power transmission equipment.

J. T. WILSON
Engineering and Development Division,
Allis-Chalmers Manufacturing Co.

As the precious seconds of totality ticked off at 22 minutes past seven on the morning of July 9th, nature set up her own laboratory for scientists, and before it was whisked away again a little more had been added to man's understanding of the long-puzzling phenomena of atmospheric electricity. The eclipse had tipped off another solar secret or two.

Alone, this day's studies would hardly loom large among man's conquests of nature's mysteries, but our own eclipse-observing expedition to this hemisphere's best vantage point in the region of Hudson Bay had a few predecessors in this challenging field of science. Yes, from it something has been added to the records, and with the new know-how, greater will be the revelation of nature's next great show.

Centuries of study in background

Since the early experiments of Benjamin Franklin and others who used kites and vertical rods to detect atmospheric changes, there has been persistent study into the nature of atmospheric electricity. Lord Kelvin, with his water dropping machine, and other investigators who used sharp points or flames or ionizing salts have shown with varying degrees of accuracy that the earth's atmosphere exhibits a gradient of electrical potential which will vary from season to season and which is influenced by certain local effects, such as cloudiness and wind conditions.

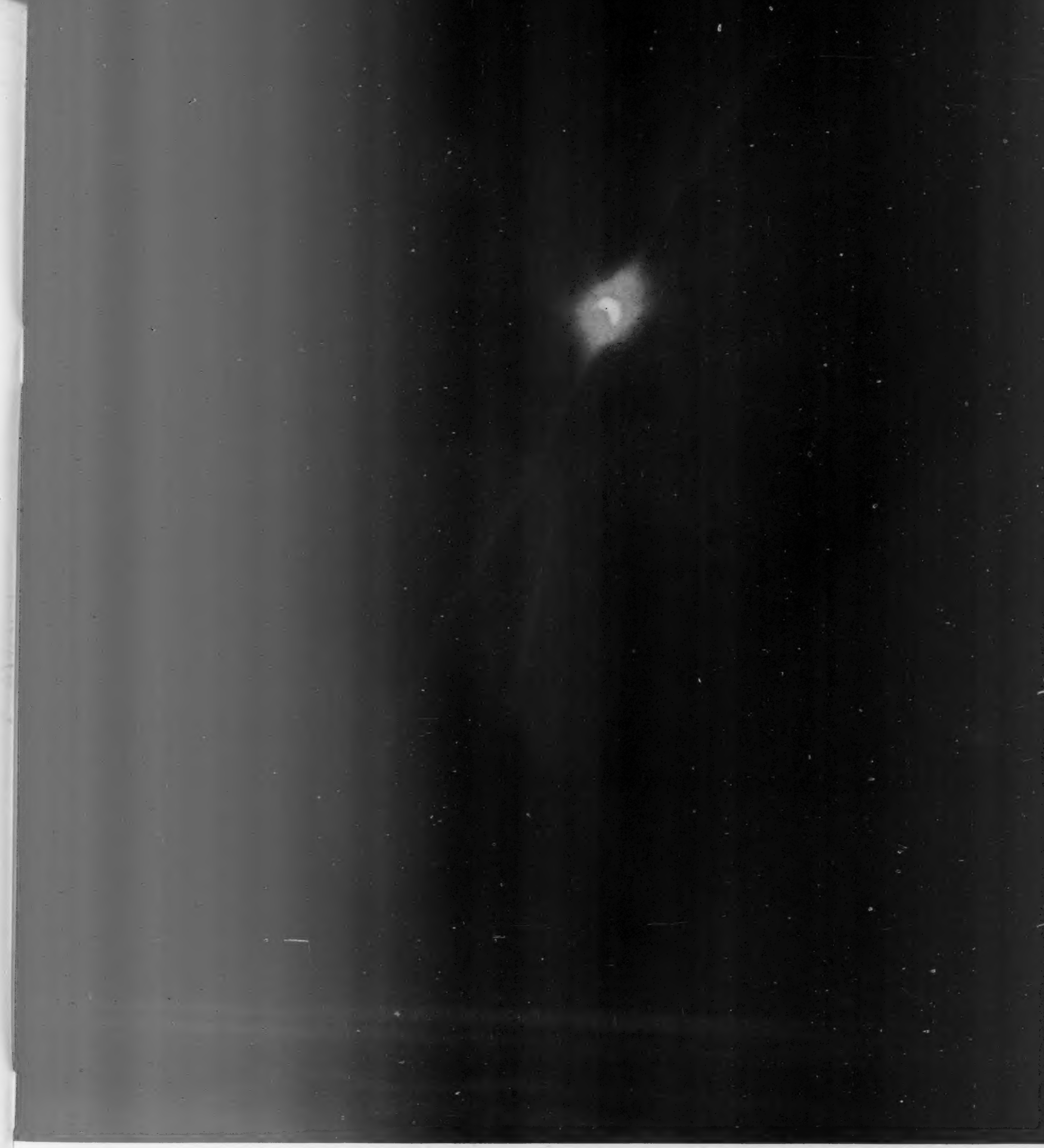
The significance of the atmosphere's potential has come more and more into prominence with the design and construction of electric power transmission equipment. The induced electrical effects resulting from heavy currents carried by the atmosphere demanded suitable control mechanisms to dissipate the effects of surges and induced direct currents imposed upon alternating-current transmission lines.

The Carnegie Institution of Washington, D. C., and other similar organizations throughout the world have made continued studies of atmospheric electricity, and as early as 1915 it was generally accepted by scientists that electron radiation from the sun might be partially or wholly responsible for many of the phenomena occurring in the atmosphere, including the aurora borealis in the arctic and also the illumination of the upper layers of the atmosphere observed in the antarctic region. A study of the changes which might occur in the atmospheric electric potential during the time of the total eclipse of the sun seemed a likely source of information concerning possible photo-electric effects in the earth's atmosphere caused by the shadow of the moon. It also seemed likely that the moon might interrupt the stream of electrons coming from the sun to the earth and this occurrence would be reflected by measurable changes in the potential gradients in the earth's atmosphere.

Choice of site is made

The expedition to the God's Lake area at Hudson Bay for observation of the total eclipse (Figure 1, page 8) was undertaken with the hope that some significant measurements concerning atmospheric electricity could be made, shedding more light upon the nature of the source and control of atmospheric electricity.

After considering various locations along the path of totality the place for these observations was chosen for the following reasons:



A CRESCENT OF SUN was revealed as the moon moved on across its face after totality of eclipse. Only 24 seconds of complete darkness were available to Physicist Wilson and his party for observations which furnished significant data concerning changes in the potential gradient of the earth's atmosphere. Calculations made afterwards indicated a definite disturbance in electrical stability of the atmosphere.

1. Weather charts from the Canadian Department of Transportation Air Services, Meteorological Division, indicated that the weather would be ideal at this locality.
2. Duration of totality of the eclipse would be longer at this point than at any other possible site for the observation on the North American continent.
3. The mining community at God's Lake, even though temporarily abandoned, would provide facilities for the maximum amount of convenience for the observers.
4. Atmospheric conditions would provide a mass of air unpolluted with industrial smoke and conditioned by blowing over large areas of land and water which was relatively free from surface dust.

After considering all of these points, the equipment for the expedition was made ready and a Canadian Pacific Airlines plane used to transport the equipment and group of observers to the God's Lake location.

The expedition was prepared to make the following type of observations:

1. Measurement of atmospheric potential gradient.
2. Bolometric measurement of the thermal radiation of the sun.
3. Sensitive measurements of the earth's magnetic meridian, employing the standard marine compass and magnetic dip needle.
4. Color photography of the events of the eclipse.
5. A record of atmospheric pressures.
6. A record of atmospheric temperatures.
7. Wind velocity and wind velocity changes.
8. Theodolite measurements for determination of position.

GREAT EXPANSES of land and water — flat country broken up by thousands of lakes — offered an ideal location for observing the eclipse. Here was unpolluted air and readily measurable wind conditions.

Weather affected observations

Many of the observed atmospheric changes which occurred during and immediately following the total eclipse may be attributed to local weather conditions, so that a thorough knowledge of these proved extremely important.

On the 15th of June, a long range weather forecast issued by the Canadian Department of Transport Air Service showed good promise of fair weather at the God's Lake area on July 9th. Weather charts issued by the Meteoro'ogical Division of this organization on July 6th also confirmed the occurrence of good weather at our chosen site for observation.

A large extratropical cyclone was slowly moving over the Hudson Bay area and the low pressure center seemed to be slowly moving northward along the east coast line of Hudson Bay. Scattered rain conditions were indicated to be on the southeast half of the extra tropical cyclone structure, and there seemed to be a slow movement of the rain areas climbing the east half of the cyclone and moving northward with the counter-clockwise wind motion typical of this meteorological structure in the Northern Hemisphere. On Sunday, July 8th, the cyclone changed its shape and began to spread, showing some signs of breaking up. However, on July 9th, the center of the structure began to move southward without breaking up, and high velocity wind brought heavy storm clouds into the God's Lake area.

It has been shown by Humphreys in his very complete treatise, "Physics of the Air," that fog, rain, and other precipitation is usually electrically charged and, consequently, nearly always modifies and occasionally reverses potential gradient measurements. Humphreys also stated that cirrus clouds and other types of fair weather clouds carried at high altitudes show little or no effect upon potential gradient measurements. These facts must be given careful consideration when interpreting the significance of changes which occurred in the potential gradient following the period of total eclipse.

Variation in wind velocity as measured at God's Lake shows excellent agreement with the weather charts, and since the flat country, broken up by thousands of lakes in this vicinity, offers no high obstruction which would change the course of the wind locally, we assumed that our measurements of direction and velocity were typical for a corresponding area in an extratropical cyclone.

The temperature of the surface ground made at the location of our instruments was 42 degrees at midnight preceding the eclipse, while the temperature of the water at God's Lake was 39 degrees at this hour. We may assume that this difference in temperature was typical of other areas in the vicinity. The difference in the rate of radiation encountered as the wind passed over the land and water was expected to produce a certain turbulence in the air masses close to the

AERIAL PHOTOGRAPHY proved invaluable to the expedition, particularly during the actual occurrence of the eclipse, when clouds obscured the great phenomena from observers on the ground for most of the time.

earth's surface, and such turbulence was indicated by gustiness noticed during all times of observations and preparation for observation.

The sky condition at God's Lake was at all times partially cloudy and the overcast was never less than 60 percent between 11:40 p. m. on July 8th and 5:30 a. m. on July 9th. At 5:40 a. m. July 9th, a mass of fracto-cumulus clouds blew south, clearing the sky and revealing high altitude cirrus clouds.

At 6 a. m. masses of fracto-cumulus and massive nimbus clouds blew from the north, bringing occasional snow and rainfall to the vicinity. The wind velocity ranged from 22 miles per hour to 45 miles per hour. The high velocity occurred only at intervals of extreme gustiness shortly after sunrise.

The temperature at the time of the eclipse had reached 39 degrees and during the event of totality the thermometers indicated a drop to 38½ degrees.

Following the period of totality of the eclipse, a steady wind from the northwest brought more heavy nimbus clouds, and intermittent flurries of snow and rain continued up to the time of our departure from the location.

Check astronomical calculations

A determination of the position of the God's Lake site was made by checking the chart of Lt. Gerald Bradley of the Canadian Mounted Police, stationed in the God's Lake village. Next, the convertible level was used as a theodolite, and position calculations were made after sighting Polaris, Jupiter, and Venus during the late evening and early morning of July 8th and 9th.

Cloudiness obscured most of the stars and planets and quick sights taken through the telescope proved our only means of checking position astronomically. Sunset on July 8th was completely obscured by clouds, and sunrise on July 9th was accompanied by such high wind as to cause unsteadiness of the convertible level. Determinations of position from the astronomical readings indicated our position to be 54 degrees, 42 minutes and 10 seconds latitude, and 94 degrees, 9 minutes and 2 seconds, longitude west of Greenwich. These measurements indicated that the site of observation was approximately 10 miles from the center of the path of totality.

The duration of totality at the center of the path should continue for 43 seconds, but due to our position, we could expect the duration to extend for 24½ seconds. If weather conditions had been ideal, we would have moved the site of observation to the mid-path of totality, but under the circumstances, this proved to be unpracticable because such a trip would involve transporting the equipment by canoe, which neither time nor the weather would permit.

The chronometer was checked with radio time signals originating at the Naval Observatory in Washington, D. C., by use of the radio set in the plane. From calculations we predicted that totality would occur at 7:22 and 10 seconds. We could expect from these calculations that totality would end at 7:22 and 34 seconds.

Errors in the chronometer may have occurred due to the temperature drop when the instrument was brought from the heated airplane into the cabin which we used for our headquarters. The chronometer variations had been studied for one month in advance at temperatures ranging from 68 degrees to 80 degrees. The temperature within the cabin varied from 37 degrees to 41 degrees, and the performance of the chronometer at these temperatures is being repeatedly checked to ascertain the accuracy of the latitude and longitude of these determinations. An error not greater than 2 or 3 miles in position determination can be assumed.

Review history of measurements

Precedents for the observations made at God's Lake are found in the history of measurements of the electrical nature of the atmosphere through centuries. A classic beginning is the experiment performed by Benjamin Franklin in 1749. Franklin's kite proved that the cloud structure was electrified with a charge which was conveyed to a metal key placed on the kite string near a reel held in this early observer's hand.

The Franklin experiment confirmed an earlier attempt by Dalibaird to make this measurement on May 10, 1752. In July of 1752, the French physicist, Lemonier, erected a tall, insulated, metallic conductor upon the top of a church tower in the suburbs of Paris. This rod was supported upon insulators composed of sulphur castings. Repeated experiments were made with crude gold foil electroscopes which proved that the rod became charged with electricity even when the sky was absolutely cloudless.

In the year of 1757, an Italian scientist, Beccaria, inaugurated a program of systematic observation of atmospheric potential. This study was continued for a period of 15 years without interruption and served as the beginning of systematic weather observations in Italy. Beccaria employed flames as collectors and also made studies with tall, vertical rods which were mounted upon insulators.

In 1855, Lord Kelvin invented and perfected the quadrant electrometer which could be used with great accuracy to measure the potential gradients. Following the perfection of the electrometer, the Kelvin water dropper was developed to increase greatly the delicacy and accuracy of electrical potential measurements.

German scientific literature records the work of Linss, who in 1887 proved that the most perfectly insulated conductors will lose their charge when exposed to air. Accurate measurements were made for the first time to prove the nature of the atmosphere's conductivity. This work was continued in the laboratories of Cambridge University in England, and in 1900, C. R. T. Wilson proved the existence of spontaneous ionization in the atmosphere resulting from high electrical potentials.

In the year 1902, Rutherford and Cooke in England and McLellan and Burton in the United States discovered the penetrating radiations coming into the lower atmosphere and concluded that apparently they had their origin in radio active substances located in the surface crust of the earth. This was followed shortly by the development of a theory by Oliver Heviside which explained reflection and bending of radio frequency waves by a strata of highly ionized air located in the upper limits of the earth's atmosphere.

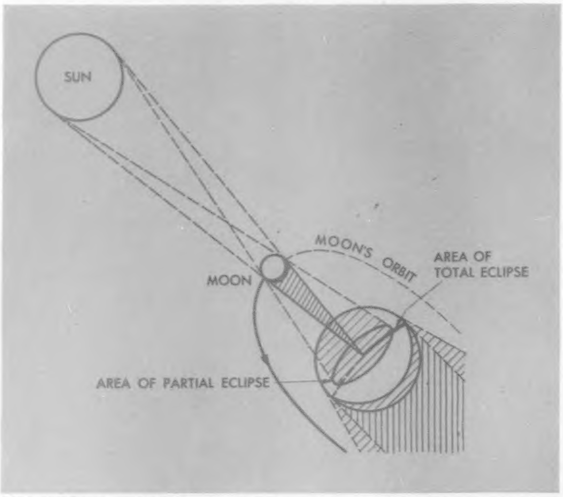
This work was quickly followed by the discovery of large and slow-moving ions in the earth's atmosphere which were thought, at that time, to be the nucleus for condensing water droplets in the clouds. The frequency of occurrence of these ions were studied by Langevin, and the Carnegie Institution in Washington began the first series of systematic observations of the potential gradient of the atmosphere upon the ocean. In 1906, the first observations of intense and powerful radiation striking the earth from the outside was observed, and in 1913, Hess and Kolhorster confirmed the existence of this penetrating radiation. This discovery was the beginning of cosmic ray study which has had great significance in the sciences of nuclear physics and astrophysics.

Potential gradient phenomena

Observations of the earth's potential gradient at various observatories scattered over the surface of the earth have indicated a diurnal variation which may have two peaks per day in the summer season and one peak in the winter season. In the tropical latitudes, the potential gradients are often found to have one single peak in the middle of the afternoon.

It is difficult for us to believe that the air which we breathe actually carries an electric charge and the potential of the charge about our heads is considerably different than that at the location of our feet. The earth is usually negatively charged and the atmosphere carries a positive charge to the earth's negative under most normal conditions.

Observatories in the higher latitudes show a higher potential gradient value than the observatories near the equator.



THE MOON'S SHADOW may disturb electrical stability of the earth's atmosphere by shadowing the earth from electrons and sunlight. (FIG. 1).

In the vicinity of the lower half of Lake Michigan, for example, the potential gradient will vary from 50 to 75 volts per meter. When a thunder storm is approaching this vicinity, we may observe the potential gradient to rise as high as 800 volts per meter, and some observers have found potential gradients as high as 15,000 volts per meter occurring during thunder storms.

The human body does not feel an electric shock resulting from the potential gradient because the air surrounding the body is a poor conductor and the slow accumulation of charges which will occur on the surfaces of the skin are conducted away as rapidly as they are collected. If we produce a high rate of ionization of the earth's atmosphere, we will increase the conductivity of the air and thus facilitate the collection of the electric charge. It is for this reason that flames or radio active substances are used in connection with the collectors in the measurements of potential gradients.

Set up God's Lake equipment

The instrument (Figure 2) used by the Allis-Chalmers expedition at God's Lake employed the radio-active element, polonium, to ionize the air surrounding a brass collector basket. The collecting basket was suspended by means of highly insulated cords at a height of two meters above the surface of the earth. A second collector basket was half-buried in the earth, and electric conductors between the two baskets brought the charge to a collector capacitor suspended by a super structure of insulated cords.

The poles which supported this apparatus played a double role in serving as a scaffold for the potential gradient device and also as stadia rods which assisted in aligning the cameras and bolometer in the proper position for observation. An electrometer tube circuit developed at Allis-Chalmers was employed to measure the charges which collected upon the capacitor.

Two oil-burning brass lamps were also carried by the expedition to be substituted for the radio-active collectors, although when tested for this purpose they proved undependable and so were not actually used during the expedition.

The chief disadvantage associated with the use of the radio-active collector lies in the slowness of its action. The collector capacitor required 45 seconds to reach its maximum charge in the God's Lake areas, a performance in agreement with a preliminary test made in Milwaukee.

The slowly accumulated charge necessitates very perfect insulation of all parts of the collector, and the adverse weather conditions encountered made it necessary to repeatedly replace the supporting cords, which had been dipped in paraffin to increase surface resistance and reduce electrical leakage. In order to refresh the paraffin surfaces a small alcohol blow torch was used, and—by brushing all the parts which were paraffin-coated with the flame—leakages were held to a minimum value.

The collector basket was suspended at a position which brought the total charge across the capacitor to 200 or 300 volts, and in order to accumulate this charge the insulation must be almost perfect. It proved necessary to insert a bakelite tube through the upper collector basket and pass a supporting cord through the tube in such a manner that the cord did not touch the basket directly. This greatly improved the insulation of the system and permitted stable performance, even though the apparatus was frequently moistened by the recurring rain storms.

It is apparent that the collector capacitor will assume a charge having a value somewhere between zero and the true potential of the atmosphere at the location of the collector basket. This will be determined by the fact that the current of electricity flowing from the collector to the earth over leaking insulation will be equal to the current which is about to flow from the air to the collector, since the latter is at a potential below the true potential of the air.[1]

Potential gradient inversion

The chart (Figure 3) which plots the potential gradient at the time of our observation indicates a drop in the potential of the atmosphere occurred beginning approximately four minutes after mid-totality. The behavior of the potential gradient was erratic, and seven minutes following mid-totality the potential showed an inversion in which the earth became positive to the atmosphere's negative charge. Considerable fluctuation occurred during the next 18 minutes, and following that time, the potential gradient rose to its apparently normal value and remained very steady for the balance of our stay at this location. In all observations made between 11:30 on July 8th and 2 p. m. on July 9th, the potential gradient appeared steady, with slight fluctuations between 150 and 175 volts per meter.

It is impossible at this time to make accurate statements pertaining to the cause of the potential gradient inversion which followed the total eclipse of the sun. However, we are justified to make a few speculations which we hope can be confirmed by future observations.

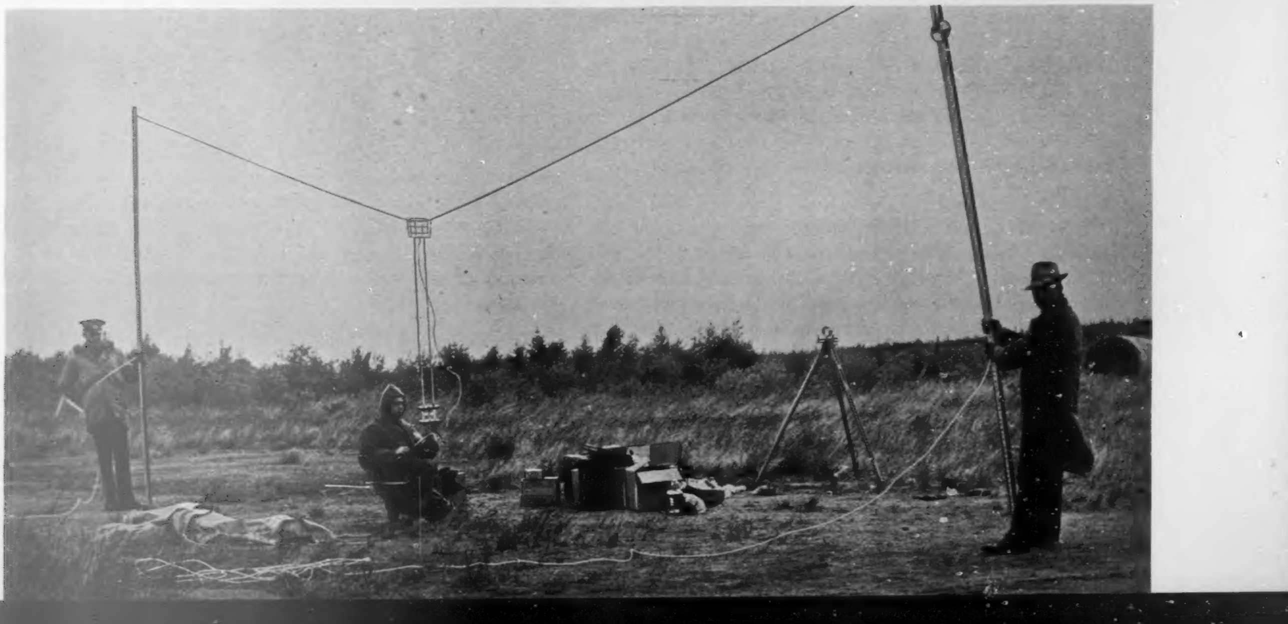
Dr. Edison Pettit, the American astronomer, has recorded the observation of eruptive prominences rising from the sun with uniform motion. However, the velocity of the prominences may be suddenly increased at intervals as they travel outward from the sun through the corona. When the velocities change, it has been noted that the new velocity is a small multiple of that preceding it. Frequently, the initial velocities are but a few miles per second. However, many short-lived prominences have been observed to exceed a velocity of 300 miles per second. Often the prominences are noted to reach an elevation above the sun's surfaces equivalent to 400,000 miles before they are dispersed and become invisible. It is entirely possible that particles and electrons which accompany the prominences travel through space and eventually reach the earth's atmosphere, and these particles may continue to travel at a velocity gained near the surface of the sun.

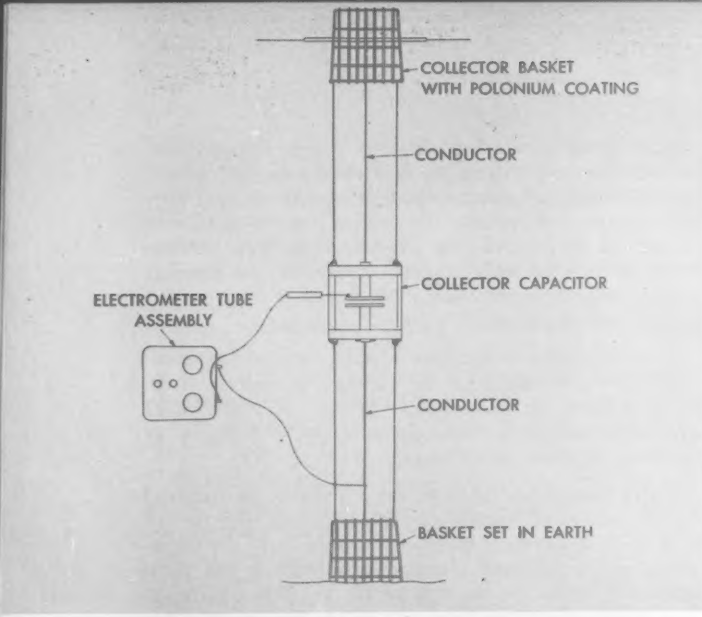
Apply astrophysical observations

Astrophysical observations also indicate that high energy electrons which may be radiated from the sun might travel at a speed approaching the velocity of light. Such bombardment from the sun would strike the earth's atmosphere at all times. Upon those areas of the earth which are turned away from the sun at any given time, we may expect the direct bombardment to cease, but the effects of gravity and the magnetism of the earth may cause some scattered radiation to bend in and strike the dark atmosphere. We could also expect that

[1] Calculations which have been suggested in the special reports of the Carnegie Institution show that even the electrical dispersion from the capacitor plates and the conductor leads will be sufficient to maintain a potential appreciably below its proper value.

POTENTIAL GRADIENT instrument used for measurements at God's Lake was supported by poles which also served as stadia rods for aligning the cameras and bolometer. Collecting basket is two meters above ground.





COLLECTOR BASKETS above and below the earth's surface — the former coated with radio-active element, polonium, to ionize surrounding air — are principal elements of this potential gradient measuring device. (FIG. 2).

the ionized layer of the atmosphere may conduct some of the charges received from the illuminated portion of the earth and tend to equalize the potential of the upper atmosphere which is in darkness.

At the time of total eclipse, the moon could be expected to interfere with the electron stream coming from the sun, and the moon's shadow might produce some change in the potential gradient which might be like that observed following sunset. In making this statement, we are assuming that the potential gradient is partially, or wholly, caused by the charges collected in the outer atmosphere and coming from the sun through inter-stellar space. The atmosphere is a poor conductor and we could expect that any considerable change in the nature of the charge in the outer ionized layer of the atmosphere might be very slow in effecting the measurable changes which would occur near the surface of the earth.

Therefore, the observations at God's Lake may possibly give us a clue as to the time required for particles traveling from the sun to traverse the space between the moon and the earth's surface. When the sphere of the moon intercepted the flow of radiation from the sun, all material which had passed the point of the moon's location before the eclipse would continue to fall from the sun upon the earth and maintain conditions typical of the sun's radiation. The space in the shadow of the moon would be void of particles radiating from the sun, and the absence of these particles in the moon's shadow could possibly be reflected by the behavior of the atmosphere potential on the surface of the earth.

If the radiation from the sun effecting the electrical potential of the earth was traveling at the velocity of light, the effect of the shadow of the moon would be felt simultaneously with the contact of the shadow at any given point in the earth's atmosphere. If measurements could have been made in the upper layers of the atmosphere at the time of the eclipse and a change were noted simultaneously with the approach of the eclipse, such facts would seem to prove that electron bombardment from the sun traveled at velocities approaching the speed of light. This hypothesis would suggest that it would be desirable to study the effects of eclipses by using balloons carrying recording potential gradient measuring devices.

The insulating effect of the earth's atmosphere may have been responsible for the delay which occurred between totality and the change in potential gradient at the surface of the earth. It is also possible that the speed of particles traveling from the sun does not approach the speed of light, and the lag could be easily accounted for if we were to assume that electrons and particles traveled toward the earth at speed comparable to the velocities at which prominences will rise from the coronasphere of the sun.

Significance of observations

The amount of data accumulated from this observation of the total eclipse and its effect is not sufficient to answer these questions. The significance of our observation lies in the fact that the potential gradient of the atmosphere did change following the eclipse, and this fact seems to indicate that a shadow of the moon passing across the atmosphere will disturb the electrical stability of the earth's atmosphere.

These observations may possibly indicate that the moon shadowed the earth from electrons from the sun as well as light from the sun; and due to a lower velocity in the electrons, the electron shadow coming from the moon lagged behind the light shadow with an appreciable angle dependent upon the velocity of electrons traveling through space.

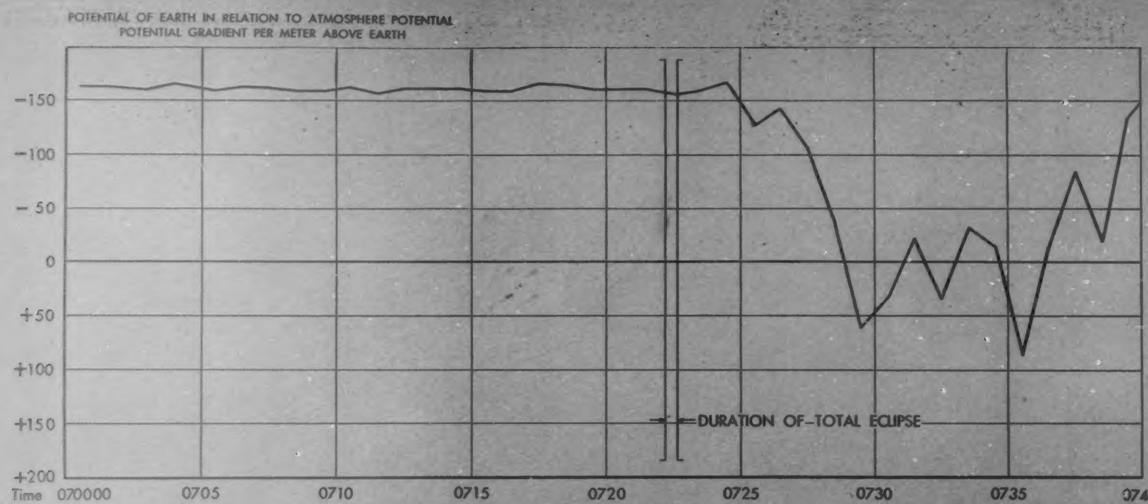
We must consider, however, the important evidences concerning the storm clouds upon the potential gradient in the earth's atmosphere. It is entirely possible that the changes in the potential gradient observed at God's Lake were caused by local cloud conditions entirely independent of the moon's shadow. However, we must point out that cloud conditions were found to be present during the hours preceding and following the eclipse, and the potential gradient indicated no radical change due to these clouds.

Thermal energies measured

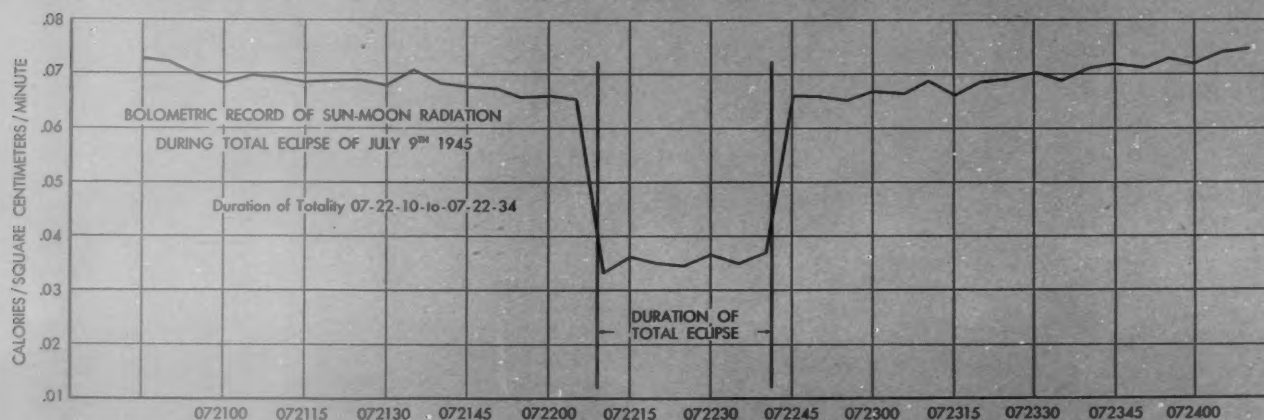
Systematic studies of the amount of energy radiated by the sun indicate that the outer atmosphere of the earth receives a mean value equal to 1.94 calories of energy per minute per square centimeter. This value is the solar constant, but due to the nature of the earth's atmosphere a very small portion of this energy reaches the actual surface of the earth.

The eclipse expedition was equipped with a bolometer, which was used to measure thermal energies reaching the earth's surface at the God's Lake location. Measurements were taken during the approach of eclipse totality, and the nature of these measurements, plotted on a graph (Figure 4), shows the drop in radiation at the time of the eclipse. This measurement was greatly handicapped, however, by the presence of clouds, and the values recorded could be expected to be radically different if the sky were clear. Nevertheless, the bolometer measurements give a clear indication of the duration of the total eclipse and are valuable for this reason alone.[2]

[2] The author has used this same bolometer assembly recently for measurement of the radiation coming from the full moon through thin clouds. Results indicate that the amount of radiation at the time of mid-totality of the eclipse through relatively heavy clouds was approximately five times the amount of radiation coming from the full moon through thin clouds. This may give some information concerning the total radiation coming from the sun and its corona at the time in which the moon actually shadows the sun.



POTENTIAL GRADIENT INVERSION followed seven minutes after total eclipse of the sun, earth becoming positive to the atmosphere's negative charge. This chart of measurements during the eclipse shows a drop in potential about three minutes after mid-totality. Considerable fluctuation continued for about 18 minutes after mid-totality, after which the potential gradient rose to its apparently normal value. (FIG. 3).



THERMAL ENERGIES reaching the earth's surface from the sun were measured with a bolometer. An appreciable drop in radiation was recorded at the time of eclipse, although radiation from the sun even at totality is greater than the radiation from a full moon. (FIG. 4).

Magnetic meridian unchanged

No changes were observed in the magnetic meridian during the time of the eclipse. The marine compass and the magnetic dip needle showed no motion or change whatsoever.

Since we do not have information concerning the heat absorption characteristics of the clouds observed at God's Lake, the values of the bolometric measurements cannot be judged. We may conclude, however, that the radiation coming from the sun during the time of totality is appreciably greater than the radiation which comes from a full moon.

It is interesting to relate, however, that during the night of July 8th a brilliant aurora appeared in the sky and, during the time of its greatest intensity, slow fluctuations were noted in the magnetic dip needle. The standard marine compass showed no changes during the auroral display.

Observation challenges future

Several of the expeditions sponsored by scientific institutions were equipped with special cameras having lenses with long focal lengths, and the records of their observations are now being studied. A photographic record of the eclipse of the sun often gives a valuable indication of the sun's condition as to its stage in the sun spot cycle. The corona of the sun seems to be greatly influenced by sun spots and magnetic storms occurring upon the surface of the sun.

The chief purpose of the expedition was to study electrical changes in the earth's atmosphere which might occur during and following the eclipse. While local conditions altered the measurements from the reaction which might be expected to take place in the atmosphere near the surface of the earth, we did observe a change in the potential gradient in the earth's atmosphere.

This certainly challenges us to make further observations at the time of an eclipse and determine if a change in the potential gradient of the atmosphere is actually caused by the moon's shadow. When these observations are made in the future, under more favorable conditions, and high altitude measurements are carried on simultaneously with measurements upon the surface of the earth, we may draw more valid conclusions concerning the nature of the sun's radiation.

EMERGENCY POWER NEEDS in the Northwest were met by giant Grand Coulee Dam, uppermost of 10 dams planned for ultimate development on the Columbia River. Two huge Allis-Chalmers 103,000 horsepower hydraulic turbines designed originally for Shasta Dam were successfully adapted here, now operate in Coulee powerhouse at efficiency of over 92 percent.

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Control That Speed!

PART III

E. H. FREDRICK and G. BYBERG
Motor and Generator Section,
Allis-Chalmers Manufacturing Co.

THE problem of operating large power units at high speeds is the most important of certain limitations in the use of a direct-current motor for speed control, as was explained in the previous parts of this article.

However, certain types of drives, using alternating-current motors as the driving unit, utilize the desirable controllable speed characteristics of the d-c machine as a means of regulating the speed of the final drive motor. Such drives as the variable frequency induction frequency converter, the Kraemer and the Rossman systems are representative of this type.

Any such system of speed control must of necessity be custom-designed for the application in which it is to be used. The drives of this type are usually limited by sound economic reasoning to the larger units. However, special consideration may make their use in small drives feasible and practical. In such instances, they may even be applied within the ranges for which straight d-c machines are available. The reduction in size of the d-c machines or the overall efficiency over a range of operating speed may give the special drive advantages in certain applications where conditions particularly favorable to the special drive exist.

Induction frequency converters

Forming the basis for one form of the special types of adjustable-speed drives quite frequently applied in recent years, the induction frequency converter is defined as a frequency changer in which windings carrying the currents of different frequencies are in the same magnetic field. An induction frequency converter is a wound rotor induction machine, driven by an external source of mechanical power, whose primary (stator) windings are connected to a source of electric energy having a fixed frequency. The secondary (rotor) windings deliver energy at a frequency proportional to the relative speed of the primary magnetic field and secondary member. (See Figure 1.)

It will be obvious from the above that this machine is the well known wound rotor induction motor, but with such modifications in its design as may be desirable to attain the required characteristics for the particular application and range of frequencies. This type of motor, which is electrically analogous to the stationary type transformer, consists principally of a single common magnetic circuit interlinking two separate electrical circuits (stator and rotor windings), between which it transforms electrical power and also converts electrical power into mechanical power.

If resistors are used in the secondary circuit, an "adjustable-varying speed drive" is obtained. However, for larger drives, such an arrangement wastes too much energy as a speed regulator, and to utilize this energy other types of counter-emf machines are usually inserted in the secondary circuit, as in the systems developed by Kraemer, Scherbius and LeBlanc.

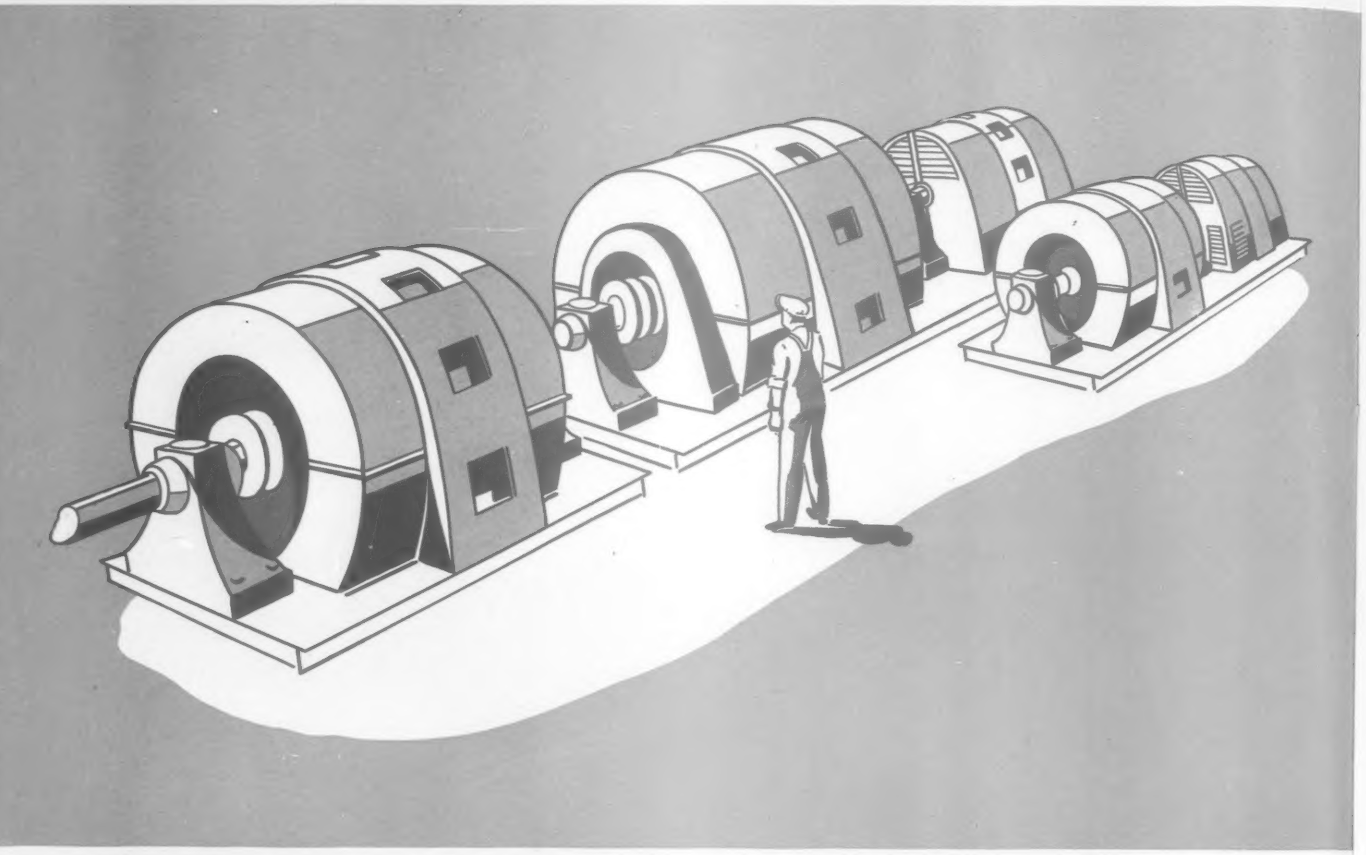
Some of the earlier uses of the induction frequency converter are largely impractical today. These include the arrangement where power from the secondary is supplied to the stator (primary) of a second induction motor on the same shaft to form a concatenated couple; or its use as a generator where it is operated at twice the speed of a synchronous machine of the same number of poles.

The frequency of the secondary or rotor winding in a converter of this type is inversely proportional to the slip of the rotor behind that of the magnetic field of the primary or stator. If the slip of a 60-cycle motor at full load is 2 percent, the rotor frequency is $60 \times 0.02 = 1.2$ cycles. At half-speed the slip is 50 percent and rotor frequency is $60 \times 0.50 = 30$ cycles; with rotor at stand still the frequency is equal to line frequency or 60 cycles. Thus, the motor is also a frequency converter, which has led to its use in the following manner.

CONTROLLABLE SPEED characteristics of the d-c machine are often effectively used to regulate speed of the final drive motor, as in the adjustable-speed induction frequency converter system described here.

For about 25 years the induction frequency converter has become more widely familiar in very small, high speed drives through its use in supplying moderately higher frequencies—for example, 80 to 240 cycles—for high speed cage motors used on wood-working machinery, portable tools, etc. Such drives require motor speeds much higher than can be obtained by the standard 2-pole, 60-cycle cage motors (3600 rpm). Even though the universal type of motor (capable of operation on either a-c or d-c) can be built for full load speeds as high as 8000 to 10,000 rpm, its no-load speeds approach double full-load speeds, and its commutator type of construction makes its use impractical for sizes larger than the very smallest drives.

Ordinarily for such constant frequency service the converter will be driven by a constant speed induction motor and will supply only one fixed frequency to the drive motor. However, for certain kinds of machine tools it may be found desirable to be able to obtain more than one speed. In a case like



INDUCTION FREQUENCY CONVERTER variable-speed system has machines in this typical arrangement. In the background at left is a variable-speed d-c motor and at right (background) is a variable frequency set. In the foreground is a constant-speed motor-generator set.

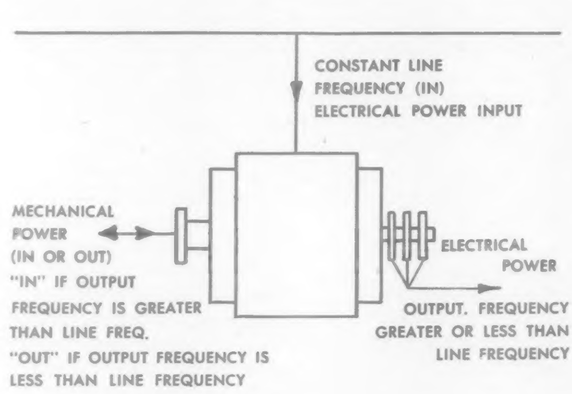
this, it is usually convenient to have the induction frequency converter driven by a multi-speed cage motor.

How to select speeds

The fixed relationship which exists between the number of poles and speed to the secondary frequency of the converter is shown simply in Figure 2. In order to be readable, this figure is limited to speeds of 1800 rpm and maximum frequencies of 240 cycles, although it should be noted that small units are built up to 3600 rpm and also for frequencies up to 400 cycles or more.

The question which arises then is, what is the proper choice of speed and number of poles to use for the converter? There are two answers to this, dependent upon whether the converter is to be driven by a constant speed motor to deliver a constant frequency, or whether it is to be part of an adjustable-speed drive to a varying frequency supply.

In the first case, the highest speed consistent with the output required will be used, which means that we shall use the minimum number of poles consistent with the required frequency. For example, if 100 cycles is desired, the obvious economical choice would be a 4-pole converter at 1200 rpm driven by a 6-pole 60-cycle cage motor.



INDUCTION FREQUENCY CONVERTER is a wound rotor induction machine whose stator windings are connected to a fixed-frequency source of energy and whose rotor windings deliver energy at a frequency proportional to relative speed of primary magnetic field and secondary member. (FIG. 1).

For adjustable-speed drives the limitations of maximum permissible speeds and speed ranges of the d-c driving motor will determine the speeds and number of poles of the converter.

How much power required

The power required to drive a frequency converter at maximum output is expressed by the equation

$$\text{Driving motor hp} = \text{converter hp output} \times \left(\frac{F2 - F1}{F2}\right),$$

where F1 is line frequency and F2 the output frequency. To this must be added the losses in the converter, consisting of windage and friction and internal losses due to the generated portion of the output.

The following indicates roughly the power required to drive a converter, operating from a 60-cycle system, at various frequencies, neglecting losses:

Secondary Frequency	Line Frequency	Power to Drive in Percent of Load HP
60	60	0
70	60	14.3
80	60	25
90	60	33⅓
100	60	40
120	60	50
240	60	75
360	60	83⅓

From this it will be obvious that for an adjustable-speed drive the lowest practicable frequency will be used to reduce the size of the driving motor and its supporting motor-generator set. This is one feature of this type of adjustable-speed drive which provides an advantage over the straight d-c drive, because in a straight d-c drive all machines must be of full size, while within the frequency converter system the regulating machines are of reduced size. True, two more machines are used, reducing the overall reliability somewhat, but for the majority of conditions the aggregate horsepower per rpm of all the machines will ordinarily be less than for the d-c drive. Hence, a slightly better overall efficiency may be expected.

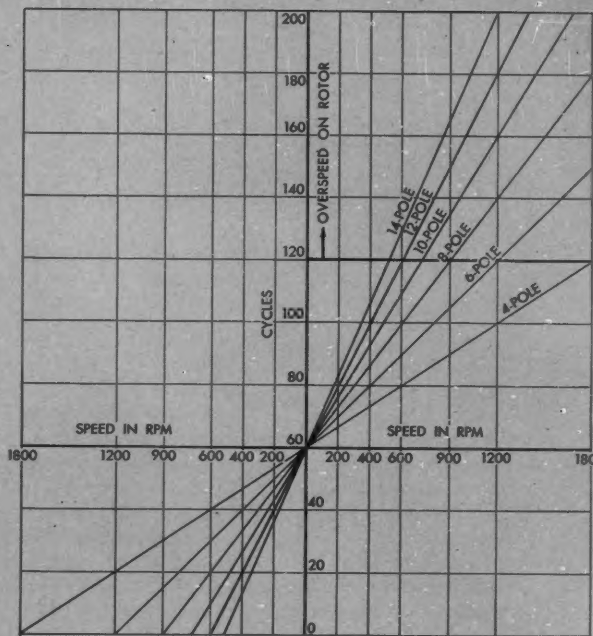
The outstanding advantage of the adjustable-speed frequency converter system occurs where requirements are for large high-speed drives. Assuming, for example, that a drive rated 3000 hp 1000/1500 rpm is required. We know immediately that a d-c motor cannot be built for such a rating. But it will be a relatively simple matter to build a 6-pole 75-cycle synchronous or cage motor for that rating and support it with a frequency converter.

Choosing economical drives

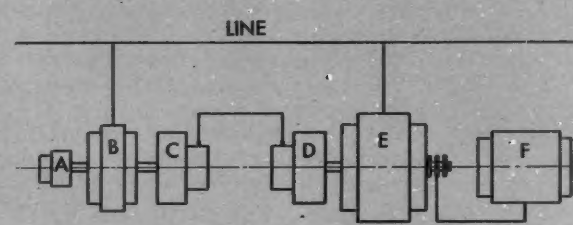
To illustrate the factors entering into the economical choice of machines for frequency converter drives, we may take a few general examples and analysis of machine selections which can be used. Figure 3 shows the general schematic arrangements of machine connections, without reference to any control or switchgear which will be required.

The proper selection of the machine combinations, from the ultimate drive motor to the auxiliary equipment, is the major problem in the application of drives of this type. Many details, some of which are independent variables, must be considered in order to make an economically balanced system. The main objective, of course, is to use the minimum of auxiliary equipment necessary for satisfactory performance.

The power output and speed of the final drive motor are

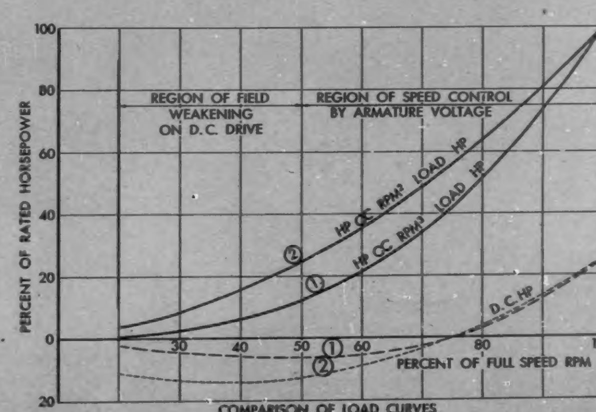


HOW NUMBER OF POLES is related to speed and secondary frequency of the converter is shown, up to 1800 rpm and 200 cycles. (FIG. 2).



A—Constant potential exciter
B—Synchronous motor
C—Direct-current generator
D—Direct-current driving motor
E—Induction frequency converter
F—Synchronous or squirrel-cage motor (final drive motor)

ADJUSTABLE SPEED frequency converter system requires this arrangement of machine connections, shown without control or switchgear. (FIG. 3).



POWER VARIATION with speed for two drives are compared here, with requirements for d-c system supporting the converter also shown. (FIG. 4).

fixed by the load characteristics of the driven machine. Therefore, the only decision required in the case of this unit is whether it should be a synchronous or an induction motor. Usually the synchronous type works out to advantage, because of its ability to compensate for part of the lagging reactive magnetizing current taken by the frequency converter, and also because it tends to maintain better voltage stability in the converter circuit.

The rating of the converter is obviously determined by the input required by the final drive motor as well as by the maximum speed at which it will be found practicable to operate. The maximum converter speed is usually dictated by the limitations of its d-c driving motor.

What driving motor?

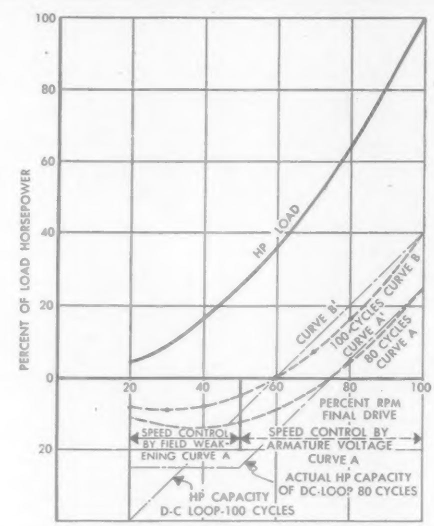
The selection of the proper converter driving motor poses a major problem. One of the factors having considerable effect on the choice of this unit is the load curve of the final drive unit. Figure 4 shows graphically a comparison between two drives (Curve 1 shows the load characteristics in which the power requirements vary as the cube of the speed; Curve 2 indicates a load in which the power varies with the square of the speed). The dotted curves indicate the concomitant requirements of the d-c system supporting the frequency converter and supplying the required mechanical power to allow operation at variable frequency.

In the regions near the top speeds of the final drive, the two curves for d-c horsepower are very nearly identical, but in the lower speed ranges the curves deviate considerably. In neither case does the required d-c power at the low speeds exceed the requirements at full speed. Therefore it is safe to say that the maximum speed point will determine the power capacity of the auxiliary loop for drives in which the load varies as the square, or higher function of the speed, which is exactly what would be expected.

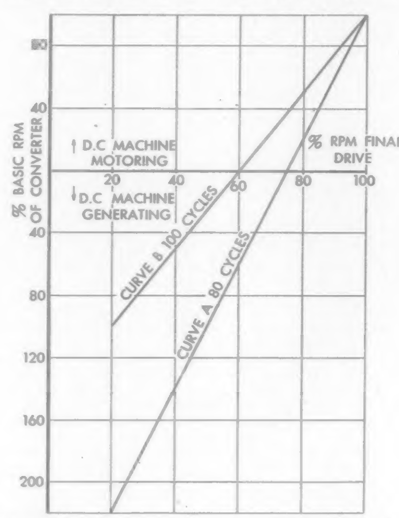
In Figure 4 indication is also made of the regions in which the speed control in the d-c loop is by armature voltage of the generator of the regulating motor-generator set, and of the region where field-weakening of the converter d-c driving motor is used to control speed. In very large drives the maximum permissible speed of the d-c motor[1] is sometimes a limitation to the extent of the range over which the speed of the drive may be regulated. However, so flexible are the components of the converter-unit, that with the choice of speeds available (see Figure 2) in the selection of the machines, almost any speed range can be obtained.

As an illustration, Figure 5 shows a comparison between two possible selections of final maximum frequencies, namely 100 cycles and 80 cycles. For simplicity only one load curve is used, since the principle is the same even though the load characteristics might be different.

From Figure 5 it will be noted that for 80 cycles the horsepower from the d-c driving motor is 25 percent of the rating of the final drive (neglecting losses due to the generated portion of the converter output). Furthermore, note that the 60-cycle point (i.e., where converter operates at standstill) occurs at 75 percent of full load speed of the final drive motor. The power demand on the d-c motor over the range of speed from standstill (at 75 percent of final motor speed) to base speed (at 100 percent final motor speed) requires that the horsepower output vary approximately with the speed (i.e., constant torque).



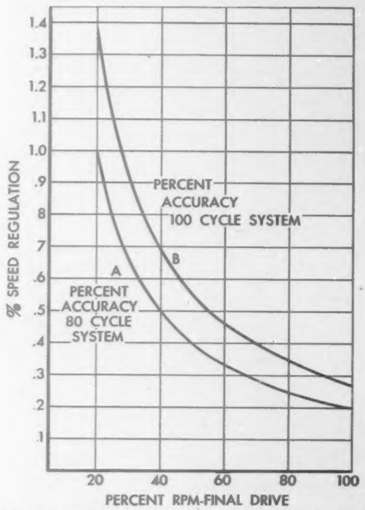
FINAL MAXIMUM FREQUENCIES of 80 and 100 cycles for a converter unit are compared. Wide speed range can be obtained. In the range from 75 to 100 percent of final motor speed, variable armature voltage must be used to regulate speed. (FIG. 5).



SPEED RANGE over which frequency converter must be driven to supply 80 and 100 cycle systems covered by Figure 5. The latter is balanced with respect to speed, while the 80 cycle range is 80 percent in the motoring direction (referred to d-c machine) but 220 percent in the generating direction. (FIG. 6).

Therefore, over this range it is necessary that variable armature voltage be employed as the means of regulating the speed. In going in the opposite direction (decreasing the speed of the final drive motor), advantage may be taken of the power capacity of the d-c loop and variable armature voltage used to bring the d-c motor to its base speed (base speed = full-field speed at normal armature voltage) in the reverse direction. At the 50 percent speed point on curves A and A'

[1] Refer to Part II of this series of articles, Allis-Chalmers ELECTRICAL REVIEW, March, 1944.



COMPARABLE ACCURACIES in speed control obtainable in 80 and 100 cycle systems with an accuracy of control of ½ percent of top speed on d-c motors indicate this is an outstanding advantage of the frequency converter system. **(FIG. 7).**

it will be readily evident that the capacity of the d-c loop materially exceeds the load demand, and since the power required is still further decreased below this point, field-weakening on the d-c motor may be used to advantage.

Speed range variations

In the case of very large drives it is possible that any speed range by field-weakening is unattainable because of certain recognized d-c motor limitations. In such cases it may be necessary to choose another maximum frequency. For illustration, Curve B of Figure 5 shows 100 cycles selected as an alternate choice. Note that the auxiliary power requirements have now increased to 40 percent of the final drive motor rating, the standstill point occurs at 60 percent of final drive speed and the range of speed control by d-c field-weakening has been entirely eliminated, as indicated by Curve B' showing the capacity of the d-c loop for 100 cycles.

To add some clarification to this, Figure 6 shows the speed range over which the frequency converter must be driven to supply the two systems covered by Figure 5. The point of importance here is that the 100-cycle system is balanced with respect to speed, with just as many rpm in one direction as in the other. Its total range may therefore be indicated as ± 100 percent. The 80-cycle range is 100 percent in the motoring direction (referred to the d-c machine), but it is 220 percent in the generating direction.

Note, however, that the ordinates of these curves are plotted in "percent of basic rpm of converter." It should be understood that the 100-cycle converter necessarily has a higher basic speed than the 80-cycle unit and therefore the apparent discrepancy between the speed ranges of the two is actually modified somewhat, so that the actual difference is not nearly as great as it appears from the curve. From the foregoing, it must be remembered that the horsepower rating of the d-c unit on the 100-cycle drive is 60 percent greater than that for the 80-cycle and its basic speed may be as high as twice that of the 80-cycle system.

System pros and cons

Of course, adjustable-speed frequency converter systems have disadvantages, and one of them is the fact that the maximum frequency is limited to certain values by the required speed of the final drive motor, since obviously only certain combinations of frequencies and number of poles will give the desired speed. These restrictions on the selection of frequency naturally are reflected in the choice of machines of the converter unit and may sometimes necessitate the use of machines which are not of the economic optimum value.

A second disadvantage, usually not too serious, is the fact that if the speed adjustment must be continuous throughout the speed range, then at the point of 60-cycle output the converter would have to operate at standstill. At this point the d-c motor delivers no power but carries sufficient current to produce the torque required to prevent rotation of the converter, depending upon the load at that point. Therefore, the commutator of the d-c motor and the collector rings of the converter would both be carrying current, and if standstill operation were maintained for any appreciable length of time serious damage to both commutator and rings might result. For this reason, the control of the d-c loop is usually arranged so that continued standstill operation is avoided and a "dead-spot" in the converter unit speed range of approximately 10 rpm in either direction is provided.

A provision necessitated by the low speed operation mentioned above, is the requirement of forced ventilation for both the converter and its driving motor. Operating at the low speeds under load there is not sufficient windage from the rotating elements to provide self-ventilation. The machines, therefore, will be incapable of self-ventilation and must be supplied with cooling air by external means. However, on any drive where the load varies at some power of the speed, the losses at the reduced speeds are, of course, less than the full load losses. This need for forced ventilation is not too serious an objection, since most large drives in modern practice are quite generally arranged for separate forced ventilation.

One of the outstanding advantages of the frequency converter system is the accuracy with which the speed can be controlled. Figure 7 shows comparable accuracies obtainable in the 80-cycle and 100-cycle systems previously mentioned. With a speed control capable of maintaining ½ to 1 percent of top speed of the d-c motor, note that the effect of the speed regulation is amplified to such an extent that at top speed on the 80-cycle system, for example, the speed can be maintained within 0.2 percent, while allowing a deviation on the speed of the d-c motor of ½ of 1 percent of top speed. Also, its speed stability closely approaches that of a straight d-c drive, so that fluctuations in load will not materially affect the speed of operation.

Altogether, these advantages and the great versatility of the frequency converter drive justify for it a definite place in the field of adjustable-speed machines. In the case of large high speed drives, it frequently offers the only possible solution while in others its first cost and operating efficiency compare quite favorably with other types of adjustable speed drives.

MODERN DESIGN (on following pages) of two 35,000 kva, 106 rpm, enclosed, self-ventilated generators complements trim architecture of the Fort Loudoun Dam powerhouse generator room. Not far from Knoxville, on the Tennessee River, Fort Loudoun is one of 28 dams on T. V. A. power system, which produces a total of 10 billion kilowatt hours annually.

Stem Voltage

P. L. TAYLOR
Circuit Breaker Section,*
Allis-Chalmers Manufacturing Co.

RECENT standardization of the impulse insulation levels of all power circuit breakers is one of the most important results of some 15 years of study and investigation made by the power companies, the electrical equipment manufacturers, and several technical committees to determine how best to:

(1) Protect electrical power systems against equipment damage, and

(2) Protect electrical power service against interruptions — due to lightning and other high voltage surges.

Covering this, the standards of the American Institute of Electrical Engineers now specify standard impulse insulation test values, as well as low frequency insulation test values for all power circuit breakers from 2.5 kv to 345 kv.

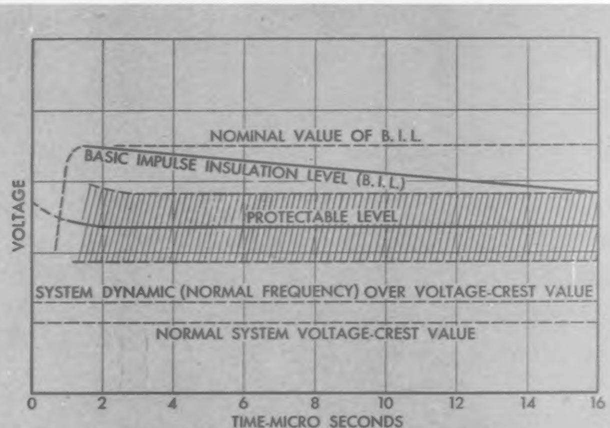
Insulation coordination

Since lightning and other high surge voltages cannot be prevented, the plan of protection is, of necessity, one in which the surge voltages are so limited and controlled, and the system insulation so correlated, that an economical minimum of damaging flashovers will occur.

The term "insulation coordination" is used in both broad and specific senses to cover only the correlation of apparatus insulation or to include the correlation of apparatus and system insulation plus the coordinated control of the magnitude and duration of surge voltages on the system. In principle, the overall plan is very simple, although its detailed application to various combinations of system conditions may be quite complex.

First, dam levels of insulation strength are built to generally uniform heights commensurate with the operating voltage and the particular local system conditions. Then, at strategic locations, surge voltage spillways or drains are provided to drain the flash floods of surge voltage before they can reach heights which will enable them to spill over the dam at some less fortunate location where serious damage or outage might result.

These drains usually consist of automatic surge discharge devices, such as lightning arresters which are designed to prevent "power follow," or the flow of normal frequency power current after the surge voltage has been drained off.



INSULATION COORDINATION VOLTAGES plotted against time show typical balance of relations, based on voltage and operating conditions, surge exposure, and insulation levels of available equipment. (FIG. 1).

Ordinarily, it is not economically feasible to establish a general system insulation level in impulse crest kv, "System Basic Insulation Level" or "B.I.L.," high enough to withstand the highest surge voltage that might be imposed upon the system if no drainage means were provided. The purpose of the drainage means, therefore, is to limit these surge voltages, by controlled discharge, to values which will not cause flashover of insulation or apparatus at undesirable locations.

The flashover value of these drainage or voltage protective devices must, therefore, be lower than the "System B.I.L.," at least throughout the time that protection is required. The value in impulse crest kv to which the surge voltage protective means can be depended upon to limit the surge voltages is called the "Protectable Level." The "Protectable Level" is usually higher than the voltage protective device flashover voltage, due to discharge drop, device location and manufacturing variations.

The "Protectable Level," in turn, should be high enough to insure that discharge of the protective devices will not occur on the normal, occasionally-applied low frequency overvoltages, such as may be due to switching or abnormal unloading conditions.

Establish voltage values

Thus, the rationalization and coordination of the insulation of a system (or portion of a system, since conditions often dictate different values for different sections) involves the establishment of values for the following voltages, bearing the best possible balance of relations to each other, in view of the system voltage and operating conditions, the surge exposure, the insulation levels of available equipment and economical considerations.

(a) System dynamic (Normal frequency) overvoltages

(b) Protective level

(c) System basic insulation level

Figure 1 shows a typical relation of these voltages plotted against time.

The system basic insulation level curve becomes the minimum limit for the individual impulse characteristic curves for any and all apparatus to be protected, as stated in the accepted definition of Basic Impulse Insulation Levels:

"Basic Impulse Insulation Levels are reference levels expressed in impulse crest voltage with a standard wave not longer than 1.5 x 40 micro-second wave. Apparatus insulation as demonstrated by suitable tests shall be equal to or greater than the basic insulation level."

It will be noted from this definition that a basic insulation level (or any impulse insulation level) is not a fixed value,

* Allis-Chalmers Boston Works, Boston, Mass.

ge Floods *on Circuit Breakers*

NEW STANDARDS for impulse insulation levels on power circuit breakers are providing new protection against damage and service interruption on electric power systems, after 15 years of investigation.

NEW DESIGN BUSHINGS, such as those installed on this indoor oil circuit breaker, enable this unit to meet new standard impulse insulation levels.

STANDARD INSULATION TESTS — POWER CIRCUIT BREAKERS (FIG. 2)

Insulating Class	Range of Interrupting Rating	Standard Insulation Tests — Withstand Voltage — Kv			
		Indoor Breakers (a) (b)		Outdoor Breakers	
		Low Freq.	Impulse	Low Freq.	Impulse
		One Minute	1.5 x 40 Full Wave	One Minute	1.5 x 40 Full Wave
		(Dry)	(Pos. or Neg.)	(Dry)	(Pos. or Neg.)
2.5	25,000 to 50,000 kva	15	45 30(c)	15	45
	Above 50,000 kva	19	60 45(c)	19	60
5.0	25,000 kva and above	19	60 45(c)	19	60
7.5	25,000 to 150,000 kva	26	75 60(c)	26	75
	Above 150,000 kva	36	95 75(c)	36	95
15	Air and oil 25,000 to 250,000 kva, also, oil 500,000 kva with 3 phases in one tank, and to comparable air breakers above 250,000 to 500,000 kva	36	95 75(c)	50	110
15	Oil breaker rated 500,000 kva and above with each phase in one tank and to comparable air breakers 500,000 kva and above	50	110(d)	50	110
23	All interrupting ratings	60	150(d)	60	150
34.5	" " "	80	200(d)	80	200
46	" " "	—	—	105	250
69	" " "	—	—	160	350
92	" " "	—	—	210	450
115	" " "	—	—	260	550
138	" " "	—	—	310	650
161	" " "	—	—	365	750
196	" " "	—	—	425	900
230	" " "	—	—	485	1050
287.5	" " "	—	—	590	1300
345	" " "	—	—	690	1550

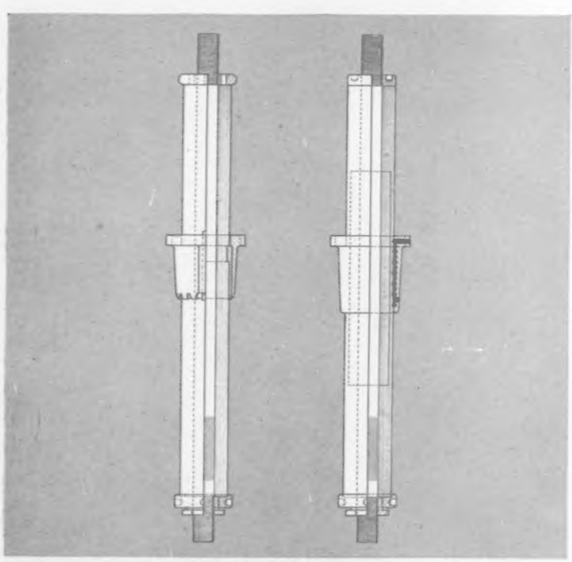
NOTES

(a) When the dielectric strength of a circuit breaker is dependent upon taping of the leads, or the use of special insulation, such taping or special insulation may be used when the factory test is made.

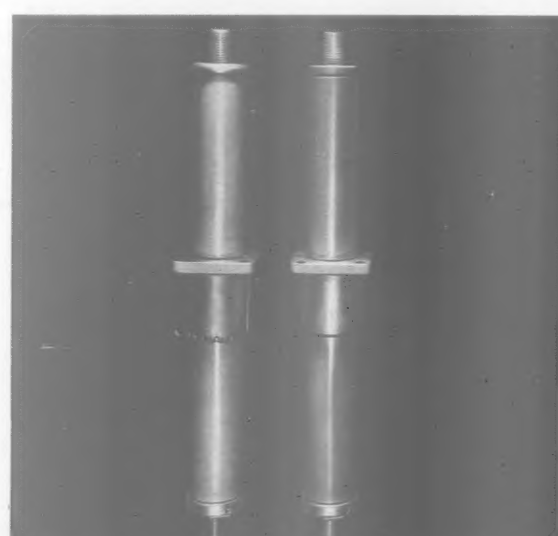
(b) For indoor breakers these impulse test values become effective July 1, 1943.

(c) Applies to tests across open contacts of magnetic-type air breakers only. These values are below the Basic Insulation Levels, but they represent present-day design practice.

(d) Where indoor breakers rated at 15, 23, and 34.5 kv are used at lower voltages, or applied on grounded neutral systems where adequate surge or over-voltage protection is provided the impulse tests may be specified as 95, 110, and 150 kv respectively. Such applications should be given special consideration.



OLD AND NEW BUSHINGS for indoor, station-type, common-tank oil circuit breakers show changes in internal characteristics. (FIG. 3).



OLD AND NEW LOOK ALIKE and are interchangeable, but only new design bushings permit breakers to meet new standards. (FIG. 4).

but is actually a curve having the characteristic shape of a 1.5 x 40 micro-second impulse wave, which rises to its crest value in 1.5 micro-seconds and decays to one-half its crest value in 40 micro-seconds. An impulse insulation level is identified by the crest value in kv of the corresponding 1.5 x 40 micro-second wave (value at time = 1.5 micro-seconds).

The characteristic shape of an impulse insulation level is, therefore, the same as that shown for the basic impulse insulation level in Figure 1. Declination with time is, incidentally, as characteristic of the voltage-time curves of natural lightning surges as of the artificial lightning surges used in apparatus testing. The voltage-time-to-breakdown curves of all insulation also show declination with time, but have very high values for very short times, and differ considerably from each other in actual shape.

The protectable level is shown in Figure 1 as a band rather than a line, indicating the variation that may be expected in practice. It will be noted that this band is more nearly level than the B.I.L. curve.

While the actual proportions of the time-voltage withstand curves of different types of electrical equipment and apparatus vary considerably, the plan of insulation coordination indicates that all equipment and apparatus be placed on a common denominator by being required to withstand a specified 1.5 x 40 micro-second wave. This means that whatever the shapes of their particular characteristic curves, these curves will all lie above the specified B.I.L. test wave, and will, therefore, meet the minimum impulse insulation level defined by that wave.

Learn surge behavior

During the development of this plan, much knowledge was gained on lightning and other surges, and great advances were made in the techniques of impulse testing and measurement. As a result of the wealth of information gained on surge behavior, it has been possible to greatly improve the impulse characteristics of apparatus insulation.

It is interesting to note that, until the development of the cathode ray oscillograph, no real recognition of surge wave shape was possible. The standards for surge voltage measurement were at various times the sphere gap, the needle gap, the rod gap, and standard suspension insulator units. Impulse insulation levels were specified as the flashover voltage of "so many inches of spacing of a standard rod gap" or "so many standard suspension insulator units."

Of the various impulse wave shapes which have been used in impulse voltage testing, all have largely disappeared from general use except the 1 x 5 micro-second wave, the 1.5 x 40 micro-second wave, and the "chopped" 1.5 x 40 micro-second wave. The "chopped" wave is merely the initial portion of an otherwise standard wave, and is used to determine insulation characteristics at very short times. The full 1.5 x 40 micro-second wave is the standard basis of reference for insulation coordination.

Raise breaker insulation levels

In order to simplify, so far as possible, the coordination of system and apparatus insulation, the AIEE-EEI-NEMA Joint Committee on Coordination of Insulation has established a set of standard basic impulse insulation level steps, each of these steps being identified with a system operating voltage class. These standard steps have found general acceptance and have been used in the formulation of the AIEE standard insulation test values shown in Figure 2. This Table includes both impulse and one-minute, 60-cycle withstand values for all standard power circuit breakers.

Rather generally accepted values for the impulse insulation levels of the higher voltage outdoor breakers which did not differ greatly from the corresponding values in the Table were in use for several years previous to the adoption of the new B.I.L. standards. On the other hand, in the case of the lower voltage breakers, particularly of the indoor types, impulse levels had not been in general use, and the actual apparatus levels were generally somewhat lower than are now specified. The more recent investigations indicated a need for a general upward revision of the impulse requirements of these lower voltage breakers.

The group of indoor, station type, common-tank oil circuit breakers rated 15 kv and below represented a particular case where the breaker impulse insulation levels required upward revision. For reasons of space economy, most breakers in this class utilize fibrous insulation, such as Bakelite and impregnated wood, almost entirely. In the design of this class of breaker, space limitations are a major controlling factor.

When the new impulse insulation level standards were adopted, it became necessary to raise the impulse levels of this group of breakers by as much as 40 percent in some cases. At the same time, no appreciable increase in breaker size was permissible, and any appreciable effect on overall breaker design was economically most undesirable.

Develop interchangeable parts

The solution indicated therefore was the development of a minimum number of new physically interchangeable parts which would raise the insulation level of the complete breaker units. Actually it was found possible to accomplish the desired result solely by the manipulation of the internal characteristics of the bushings to obtain the proper electrical stress distribution.

The new line of bushings is of one-piece insulation construction provided with a single mechanically and electrically integrated concentric metalized control layer near the outer surface of the insulating body.

In the new bushing design, the mounting flange construction was changed from a clamped, recessed, split-ring arrangement, to a simple flange cemented to the bushing body with a special magnesium oxychloride cement. Both flange and bushing body are grooved in two directions to provide rotational and longitudinal locks. This resulted in a considerable saving of critical metal, as did the replacement of the brass bushing top cap with an insulation cap of similar dimensions.

Figure 3 compares a section of one of the old standard bushings, used in indoor, station type, common-tank oil circuit breakers rated 15 kv and below with a section of the corresponding new bushing which replaced it.

The old and new bushings are identical in overall and mounting dimensions for each step in the line, and are physically interchangeable. In fact, corresponding bushings can hardly be distinguished from one another, as shown in Figure 4, yet the same breakers equipped with the new bushings meet the new standard impulse insulation levels.

PROGRESS toward a better lightning-proof transformer continues as the transformer design engineer gains more and more control over the abuse unleashed by an electrical storm.

Transformers are Winning

Fight to Lick Lightning

L. C. AICHER
Transformer Section,
Allis-Chalmers Manufacturing Co.

TODAY the ability of a well-designed transformer to withstand high voltage surges is recognized as one of its most important qualities. Much time and effort has been directed at the designing and building of transformers that will withstand much of the abuse unleashed during an electrical storm.

Designing transformer insulation to withstand the abnormal voltage conditions encountered in service involves not only a knowledge of the magnitudes of voltage, but also of the vagaries of insulating materials.

The importance of the serviceable life of a transformer was recognized long ago when minimum standards of transformer insulation were established. Out of experience grew a common practice of extremely heavy padding with insulation of the line end turns of high voltage transformers. Some line coils were wound of heavily insulated cable.

These solutions of the problem were commendable in their day, a fact borne out by the service record of many thousands of kva of transformers built along these or similar methods. But modern methods insure higher strength with less of the same insulation.

New lab instruments adapted

In the decade of the twenties, utility and manufacturers' engineers directed considerable attention to the effects of lightning on transmission lines and transformers. A serious handicap existed for some time because little was known of the nature of lightning. Furthermore, lightning was elusive and of such voltage, current, and speed that conventional measuring instruments were valueless. Several attempts were made to duplicate the effect of natural lightning with laboratory equipment, but before a suitable measuring device was available. Needle gaps and small sphere gaps were connected between points in a transformer winding and adjusted until they sparked over when a similarly measured voltage was applied. Although today it has been superseded by other methods, this procedure produced valuable data in that period.

In the late twenties a device that showed great promise emerged from the "curiosity" laboratory. The possibilities of the cathode-ray oscillograph were quickly appreciated and diligent effort produced one which could keep up with the vagaries of lightning. Though a decidedly tempermental tool in its early days, it did provide the engineer with something he could use to measure quantities previously beyond his reach. Further, he could obtain a permanent record on a film which could be studied time and again as his analysis developed.

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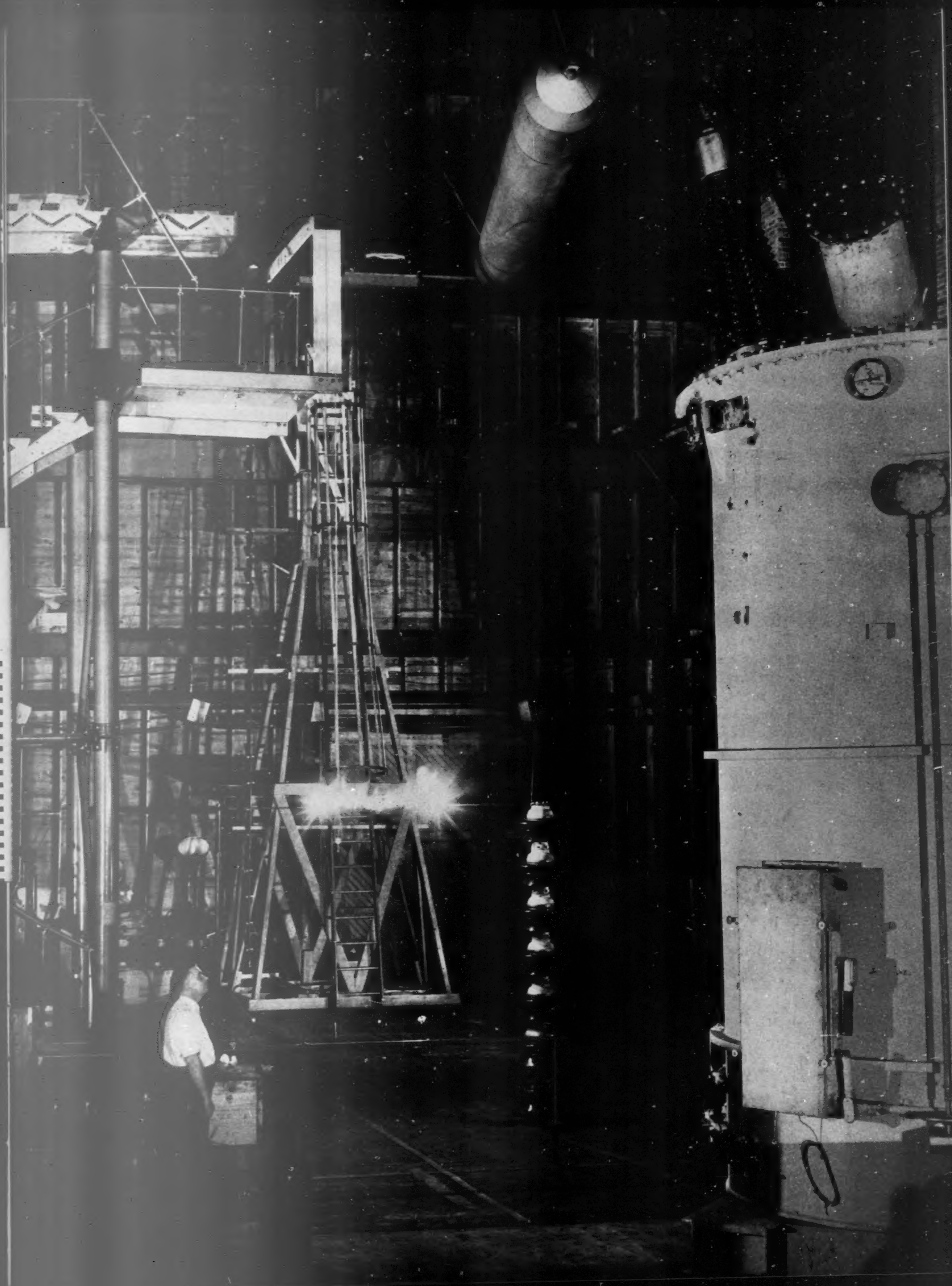
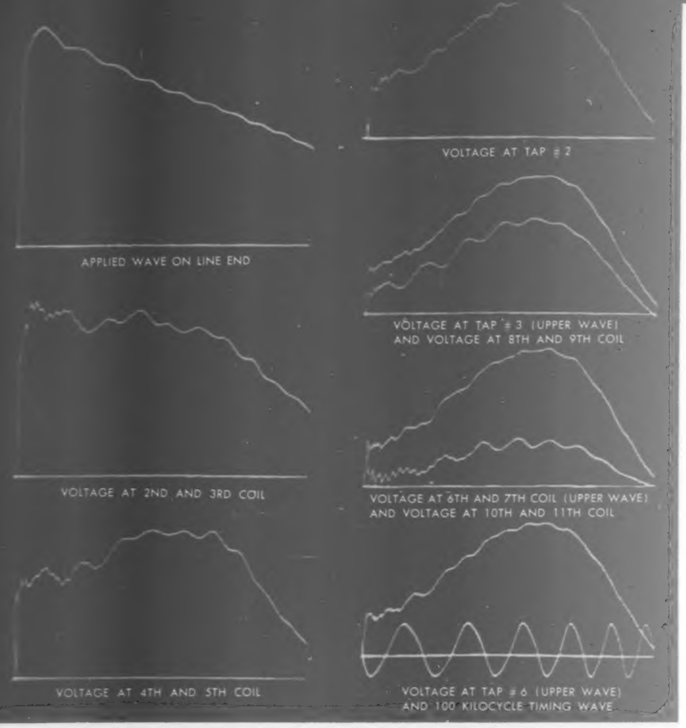




VOLTAGE OSCILLOGRAMS like these can be compared with crest of applied wave and voltages between any two points obtained. (FIG. 1).

The early thirties found a commercial version of the cathode-ray oscillograph in several high voltage laboratories, together with a surge generator. The laboratories were each investigating the phenomena within transformers associated with artificial lightning voltage transients. The characteristics of insulating materials when subjected to similar impulses of voltage were collected.

Conducting so thorough a study of the voltage stresses within transformer windings and the behavior of insulating materials when subjected to similar voltage impulses has involved numerous problems. The degree of success already attained in designing "lightning-proof" transformers has resulted from significant developments in many directions, and a review of them is really the story behind the present-day ability of the modern transformer to withstand effectively high voltage surges.

Measure transient characteristics

One such essential development involved the accurate measurement of transient characteristics. How are the transient characteristics of a transformer measured?

An impulse voltage distribution test consists of measurements that show how much voltage exists at and between any choice of points in the winding. An actual transformer core and coil assembly has repeated impulses of the same magnitude and shape applied to the line terminal of the winding. Different points in the winding (generally series connections between coils and tap leads) are connected one at a time to the oscillograph and their voltage measured, one point for each voltage impulse applied.

A series of voltage oscillograms similar to Figure 1 is obtained. These can be readily compared with the crest of the applied wave on a percentage basis and the nature of the voltages occurring to ground, between coils, between windings, between taps, in fact between any two points is available. The magnitude of the voltage at each instant of time is permanently recorded.

A distribution test is conducted at a voltage sufficiently low to avoid damaging the insulation in the transformer. So long as the shape of the test wave is the same, the percent volts between points are reproduced faithfully regardless of the actual magnitude of the applied voltage. Therefore, if in the distribution test shown in Figure 1 we find 10 percent voltage between two points, we can expect 10 percent of the applied voltage or 75 kv, if the specified impulse test for the transformer is 750 kv. The insulation between these two points must be good for 75 kv plus suitable safety margins.

Shell type transformers have inherent advantages for high voltage applications, as has been borne out by numerous voltage distribution tests conducted on actual as well as model transformers. Core type transformers inherently have a less desirable voltage distribution characteristic, though proper design can produce a core type transformer possessing a suitable characteristic.

From time-to-time one hears or reads of the theoretically perfect transformer, the design of which produces an absolutely uniform voltage distribution even under surge conditions. This is usually more fictional than real because, as in all engineering, an economic balance must be attained. In fact, it is not desirable to use methods or to install devices which themselves introduce hazards, nor is it essential that the distribution be perfect. While it is desirable to improve the distribution by design technique, it is more important to know what voltages exist under transient conditions and how to insulate for these voltages most economically. For this reason a properly designed core type transformer sometimes results in a saving of materials over a shell type unit to fit the same operating conditions.

Before the day of impulse strength requirements, many shell type transformers were designed with three and four and sometimes more high voltage sections of coils and correspondingly five or six or more low voltage sections. Such a design allows a maximum of flexibility in reactance control and low eddy current losses in the winding conductor but is generally not the most economical since it requires a greater quantity of insulation. A modern impulse-proof transformer seldom has more than two high voltage sections and the corresponding three low voltage sections. Again, reactance and eddy current requirements influence the choice.

Transposition of strands within the coil during winding aids in reducing eddy current losses where fewer coil groups are used.

Early insulation coordination

Much has been published about the insulation coordination of electrical systems and basic insulation levels. How does this affect the transformer design?

Years ago when transformers were damaged, the matter was attributed to its being struck by lightning. Later, how-

ever, it was learned that all damage was not done by lightning striking the transformer. Instead, it struck the transmission line many miles from the transformer, and in other cases it struck in an open field some distance from the line. The induced voltages on the line caused by strokes in the vicinity of the line could be as destructive as those on the line or the direct strokes on the transformer bushings. The voltages appearing on the line, either as direct strokes or induced by strokes, travel along the line in each direction and are known as "traveling waves" of voltage. When the magnitude of the traveling voltage wave exceeds the dielectric strength of the insulating medium, a discharge takes place. If the transformer is the weakest point on the line, it fails — causing considerable economic loss.

It was reasoned a transformer should be designed to be stronger than other parts of the line. This established the early practice of specifying levels of impulse strength requiring transformers to be stronger than specified lengths of insulator strings used on the transmission line. A standard rod gap of definite dimensions and bushings was also used as a standard of impulse levels in years past.

As was learned later, these devices possess impulse voltage characteristics that are dependent upon the atmospheric conditions of the moment. Like sphere gaps, the relative air density affected the flashover voltage of each device, and unlike sphere gaps, the moisture content of the air, measured as humidity or vapor pressure also has an effect. Further, it was learned that each device had its own vapor pressure characteristic. It was an easy matter to specify impulse strength as more than that of a string of so many insulators, or a gap of so many inches or a bushing under standard atmospheric conditions. A demonstration of this strength in the laboratory was another matter.

When the standard rod gap was used as a measure of strength, each voltage class of transformer was assigned a gap spacing in inches. The atmospheric conditions in each test laboratory varied from day to day, as nature dictated, so it is obvious that the same voltage class of transformer was tested at various voltage levels. This was an undesirable condition and was corrected in 1937 with the adoption of specific minimum voltage levels to which each voltage class of equipment was to be tested. Present-day standards follow the precedent of 1937, with minor variations.

Building impulse strength

Next, how is impulse strength built into a high voltage power transformer?

One approach has been the redesign of insulation assemblies. Many of the changes have been slight, but their accumulative effect has made them well worth while.

Important factors are the materials used in coil insulation assemblies. These are still predominantly paper, fullerboard and oil, synthetic materials not having proven themselves as yet. The greatest changes, however, concern how the materials are used to develop their maximum strength.

Before an insulation assembly can be designed some idea of the stress to be encountered must be known. The ASA standards specify the commonly applied 1.5 x 40 micro-second impulse tests consisting of a reduced voltage full wave, two chopped waves and a final full wave. Some purchasers of transformers also require steep wave impulse tests in which the voltage rises at a rate of 1000 or more kv per microsecond and is chopped by a gap on the rising front of the wave.

All transformers are designed to exceed the ASA impulse tests for their respective voltage class, as well as the accepted steep wave tests.

A full wave test imposes voltage stress on the entire winding. Voltage differentials occur between turns, between coils, between sections, between taps and from all parts of the winding to ground. It is the most severe test for the winding as a whole and is the test which generally decides whether a failure has occurred. The full wave voltage determines the insulation to ground for nearly all the winding exclusive of the line end and it determines the coil-to-coil stresses of the coils near the grounded end of a winding.

The chopped wave test determines the stress between turns in the line-end coils and between coils near the line end of the winding and from the line end to the ground. Its severity depends upon the magnitude of voltage, the duration of the voltage before it is chopped by the gap and the transformer characteristic, the last two factors determining how far the voltage penetrates the winding. The ASA minimum time-to-flashover assures that insulation is subjected to a desired voltage stress for a specified minimum length of time. If the time to chopping is extremely long the transformer will receive an excessively severe test.

In most voltage classes the line-end turns and coils receive their most severe test when a steep wave test is applied. Whether the greatest stress occurs between turns or between coils depends on the electrostatic control of voltages built into the winding, as sometimes controlled by shields or plates and the geometric configuration of the winding and insulation assembly.

All transformers built to present ASA standards have a steep wave strength which is generally recognized. There are steep wave tests in use that require added insulation strength, but these test levels can be provided for by proper design.

The collective efforts of a number of circuit theorists with the necessary mathematical knack have produced theoretical methods of calculating the voltages within transformers when subject to transient phenomena. Some analyze the transient condition into a number of sine waves of voltage. Another method combines all the waves into a complex trigonometric series while a third keeps all terms in their exponential form. All depend on the same design data and with proper translation all can be shown to be equivalent. Voltages calculated by these methods have been verified by voltage distribution tests.

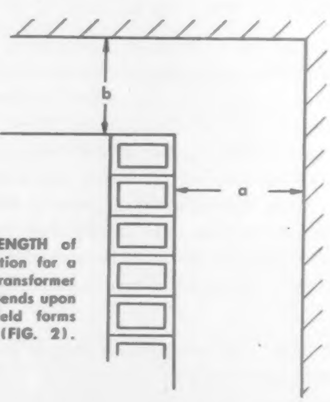
In some cases distribution data of the most nearly similar arrangements available are used as a basis for voltage determinations. Scale models can be built and voltage distribution data derived from them.

Some transformers are so complicated and so infrequently encountered that parametric evaluations for calculation methods have not yet been derived. In these cases distribution data of the most nearly similar arrangements available are used as a basis for voltage determinations. If the proposed design is a radical departure from available data, scale models can be built and voltage distribution data derived from them.

Electrical insulation, like a chain, is no stronger than its weakest link. The weak link in an oil-insulated transformer is the oil itself, assuming all solid insulation is properly processed. Electrical breakdown progresses in oil after ionization is present. Therefore, it is obvious that to develop strength with oil present it is necessary to keep the voltage gradient in the oil below its ionization point. Effective control of the gradient is obtained by proper geometric relationship of parts where there are high voltage differentials combined with the use of solid insulation to produce the desired result.

The shape of the dielectric flux field influences the magnitude of voltage that will cause a disruptive discharge through or over insulating material. This is well demonstrated when a sphere gap and a rod gap are compared, with air as the dielectric. A pair of spheres produce essentially a uniform electrostatic field in the space between them, and consequently can withstand a maximum voltage for a given spacing. The rod gap, conversely, because of its geometry produces a non-uniform field, and for a given spacing its critical voltage is much less than for the sphere gap. With 1.5 x 40 micro-second negative impulse waves the critical voltage of a 200 cm sphere gap with 60 cm spacing is 1346 kv and of a rod gap of equal spacing is 465 kv.

Similarly, in a transformer, dielectric field forms must be considered wherever there are differences of potential. Figure 2 can represent a corner of the window through the core. The distances a and b are taken up by major insulation between the winding and the grounded core. The dielectric strength of the insulation in space a depends upon the distance b, and as this field changes, the strength of this corner assembly changes. There are optimum values of the ratio a to b for the different types of transformers.



DIELECTRIC STRENGTH of the major insulation for a corner of a transformer core window depends upon the dielectric field forms at a and b. (FIG. 2).

Methods of electrostatic flux control have been developed to improve the voltage distribution during the first fractions of a micro-second after the transient voltage is impressed. This is accomplished by properly placed and shaped static plates or rings, as determined by calculation and test.

Dielectric strength of materials

Sixty cycle strength data is more or less commonly used by all design engineers. Some designers, particularly of transformers, also think in terms of 120 cycle or some other elevated frequency as used in transformer induced voltage tests. It has been demonstrated that the dielectric strength of the commonly used insulations at these elevated frequencies are below the 60-cycle strength.

Innumerable tests on materials have firmly established the fact that many of the commonly used insulating materials possess considerably higher breakdown levels when impulse voltages are applied. Further, it is known that these levels depend upon the shape of the impulse wave — the rate of voltage rise and its rate of decay. The ratio of the crest of these impulse breakdown levels to the 60-cycle crest voltage at breakdown is known as the impulse ratio of the material. As an example, fuller-board and oil in combination has an average impulse ratio of 2.2.

Another complicating property of most dielectric materials when subject to impulse voltages is the volt-time characteristic. In fact, the phenomena giving rise to the impulse ratio previously mentioned are a part of the volt-time characteristic. Upon raising the impulse voltage to levels higher and higher above the critical or minimum voltage which causes breakdown, failure occurs at shorter and shorter times. This is illustrated in Figure 3. The upturn (as this rising curve of voltage is called) starts at different times and increases at different rates, depending upon the dielectric material in question, the test wave and the shape of the field. Curve A of Figure 3 shows the relative upturn of an assembly typical of a high voltage barrier which contains considerable solid material. Curve B is typical of a low voltage barrier that is largely oil. Figure 4 shows similar characteristics for the 200 cm sphere and rod gap mentioned earlier.

If the impulse voltage is raised sufficiently, the strength of insulation at rates of rise of 1000, 2000, etc., kv per micro-second is obtained.

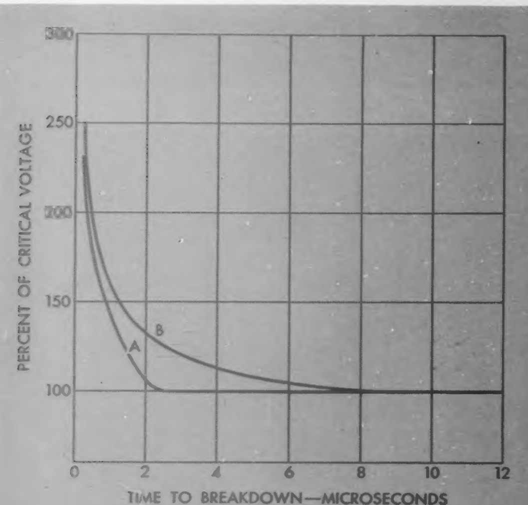
All materials do not possess the degree of upturn illustrated in Figure 3. For example, conductor insulation has a negligible amount of upturn. This fact cannot be overlooked in the making of a coordinated design. Similarly, in other insulation assemblies, like leads from the coil to bushings and to terminal boards or tap changers, the terminal boards and the bushings have their respective volt-time characteristic. All of these must be known and properly applied in the design stages. The neglect of only one can cause a failure during an impulse test.

Influence of cooling

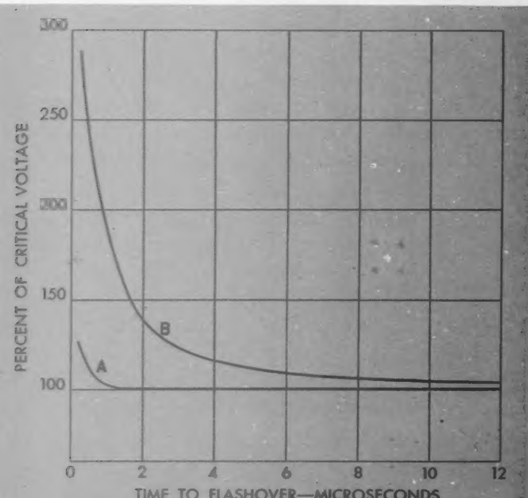
The inevitable losses in the core and coils requires consideration by the insulation designer to provide essential cooling.

In an oil-immersed transformer this requires paths through which the oil can move to carry the heat away.

Insulation assemblies that provide paths for oil flow consist of alternate thicknesses of oil and fuller-board, with an oil duct generally adjacent to each coil face to cool the conductor. The insulation strength of a barrier of this type depends upon its thickness from face-to-face, while strength of similar barriers in a uniform dielectric flux field varies approximately as the two-thirds power of the thickness. In designing insulation assemblies it is necessary to know that voltage distributes itself through such a barrier inversely as the dielectric constant of the materials.



VOLT-TIME CHARACTERISTICS of a high voltage barrier (A) with considerable solid insulation and a low voltage barrier (B) mostly of oil are shown above. (FIG. 3).



GAP VOLT-TIME CHARACTERISTICS (1½ x 40 negative waves) represent (A) a 200 cm sphere with 60 cm separation and (B) a standard rod gap with 60 cm (23.6 inches) separation. (FIG. 4).

Graded vs. full insulation

The same impulse test voltage is applied to transformer line terminals of a given voltage class regardless of whether the winding is fully insulated or of graded insulation. In either case, one end of the winding is grounded while the impulse voltage is applied to the other end. Since the entire winding of a fully insulated transformer is insulated for line voltage to ground, it is reasonable to expect, and it is true, that the impulse test imposes no special requirements of insulation sufficiency for voltages to ground.

A graded insulation design is different. As its name implies, the insulation to ground is graded from line voltage to some lower level, depending upon operating conditions. If the neutral of a 138 kv transformer bank is operated solidly-grounded, the neutral might be reduced to the insulation level of the 15 kv class. A natural thought would be to grade the insulation of such a job uniformly from the line to the neutral. However, this is not the case, for if practiced, the transformer would fail on impulse test.

The natural period of the winding infers an oscillation excited by the shock of the impulse wave. The gyrations of this oscillatory voltage superimposed upon the dynamic voltage give rise to peak voltages equal to the sum of these instantaneous voltages. These can amount to considerable voltage under some conditions and obviously require a corresponding amount of insulation. The insulation between coils and on the conductor is little different between the full insulation and the graded insulation design. The variations that occur originate from the differences in capacitance and inductance occasioned by the different geometric relationships.

Proof of the design

What is the proof that all this has been built into a specific transformer?

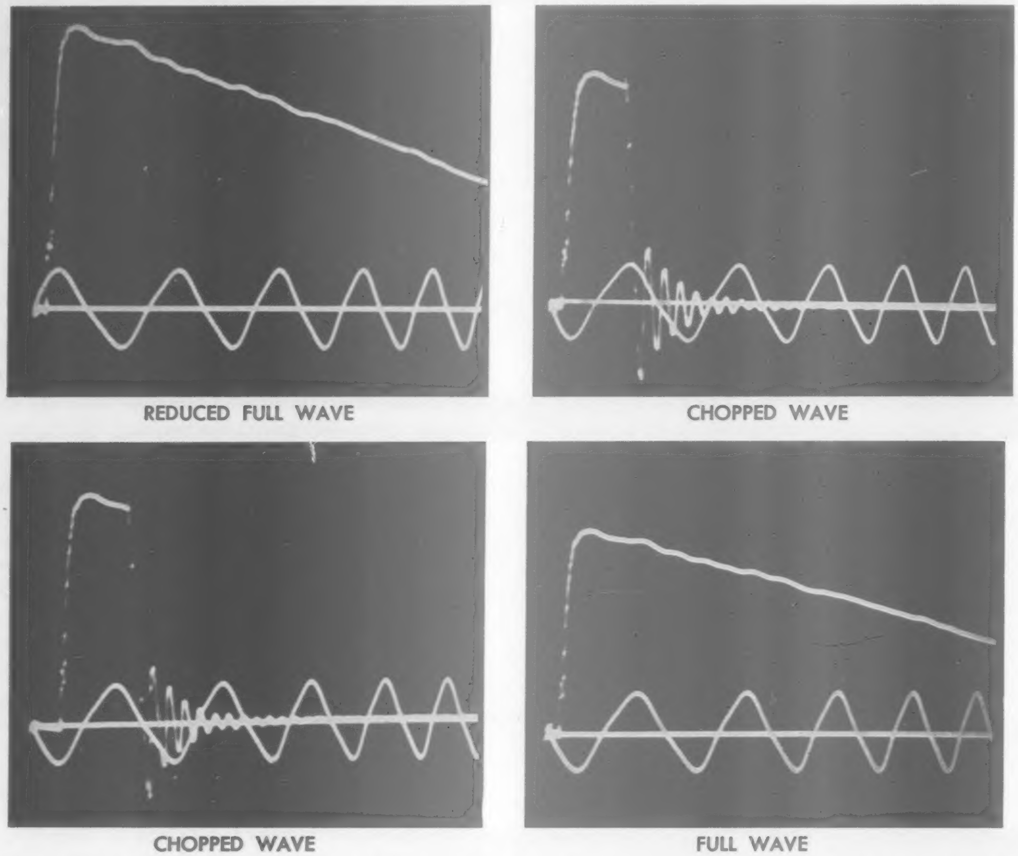
First, if the transformer has passed the recognized ASA impulse tests there is every reason to believe it will give excellent service in the field. The factory impulse tests are generally much more severe than will ever be encountered in service on a modern transmission line. Typical oscillograms from such a test are shown in Figure 5.

Secondly, and probably most important, is the field service record. A field operating record of not a single lightning or switching surge failure in 14 years of building surge-proof transformers is a dependable precedent. Transformers with windings of every voltage class up to and including 230 kv are represented in this experience.

Stress failure detection

As would be expected, 14 years have produced much experience in the conduct of transformer impulse tests. As new conditions arise, new techniques have been developed. The testing equipment is constantly being improved.

Probably the most important part of impulse testing is failure detection. Much thought and experimentation has taken place in efforts to improve failure detection methods. At this writing, experience at reading oscillograms, together with knowledge of the expected wave shape of the design tested, is the most reliable failure detector.



A.S.A. IMPULSE TEST OSCILLOGRAMS are a reliable record of transformer's ability to withstand lightning or switching surge voltages. Of those shown here, the upper left oscillogram was recorded with a different potentiometer ratio than the others. (FIG. 5).

Normal voltage excitation has been a part of impulse testing almost since its beginning yet power follow during an impulse failure seldom occurs. In fact, experience has shown that when excitation is omitted (as it always is after a test failure is suspected) the accuracy of failure detection is improved.

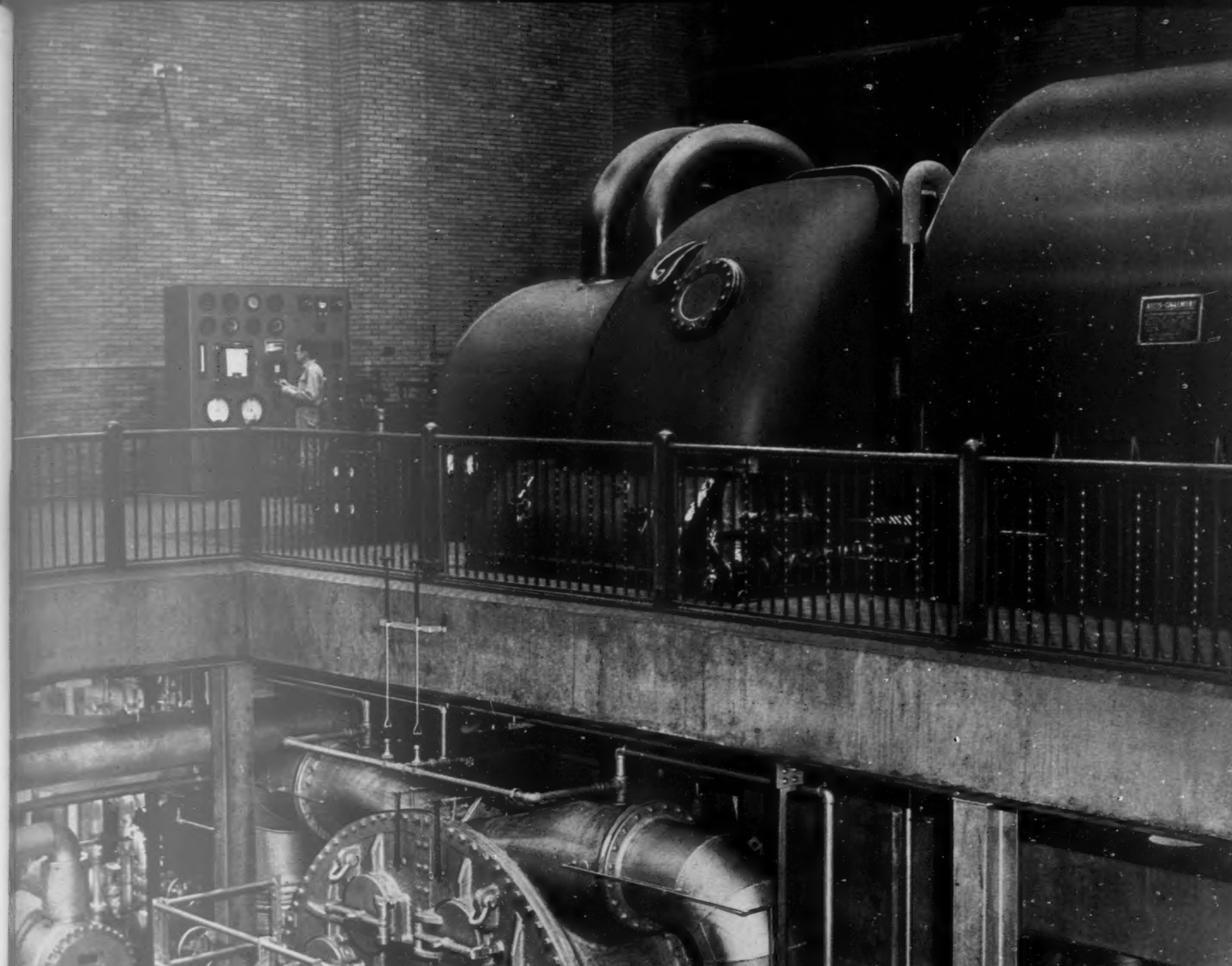
This follows from the fact that a number of susceptible circuit elements — such as all excitation facilities, including generators, lightning arresters to protect the generators, switchgear and step-up or isolating transformers — are eliminated. Within the surge generator circuit, isolating gaps and fuses or other power current interrupting devices can be omitted, eliminating their undesirable disturbance from the oscillograms.

The use of damping-means in the measuring circuits to control superfluous natural oscillations occurring in this circuit of the unloaded generator is undesirable, since such devices obscure the very type of fluctuation that results when some types of failure occur. Experience has shown that all failures do not release smoke and bubbles that rise to the surface of the oil, nor do all failures produce noise.

Since the cathode-ray oscillograph has proven the more dependable indicator of failures, experiments are being conducted with additional methods using the oscillograph in efforts to develop better and faster failure detection methods. Normal voltage excitation is being omitted from these methods.

Thus, year by year, knowledge of voltage stresses within transformer windings, the behavior of insulating materials when subjected to lightning phenomena, and the technique of impulse testing have been improved. Transformer insulation standards have undergone changes. The manufacturers have changed their design practice accordingly, and will continue to change as more is learned. Service conditions, too, are likely to change and eventually reflect upon the design, manufacture, and test of the transformer.

Yet, the field of transient phenomena and impulse testing is still wide open for progress. No better example of this could be given than the year-in and year-out operation of the high voltage laboratories on a continuous program of research and development . . . on materials, methods of construction, and tests of the theory of transient phenomena in transformers.



HYDROGEN COOLING DEVELOPMENT in turbo-generators is illustrated by this 20,000 kw, 3600 rpm condensing impulse reaction steam turbine generating unit installed recently for a midwest utility. (Hydrogen cooling aspects of the generator are discussed on the following pages.) Below is the 18,250 square foot surface condenser.

Hydrogen Keeps 'em Cool

NEW HYDROGEN-COOLED UNIT installed recently at Ohio River station of Southern Indiana Gas and Electric is in the foreground above, with the older, air-cooled machine in the background. Ratings are identical. (FIG. 1).

V. J. EGAN
Motor and Generator Section,
Allis-Chalmers Manufacturing Co.

AIR MAKES WAY for hydrogen as a cooling medium in many modern turbo-generators, reduced windage losses, quieter operation and longer insulation life marking it for wider use even for smaller units.

HYDROGEN cooling of turbo-generators—an outstanding development of the past 25 years in the electrical machinery field — has through these years proven a highly satisfactory replacement for air as a cooling medium in the larger units and just recently has been successfully applied to units as small as 18,750 kva. Such advantages as reduced windage losses, quieter operation, and longer insulation life will be possible through the wider use of the hydrogen cooling that is anticipated for the future.

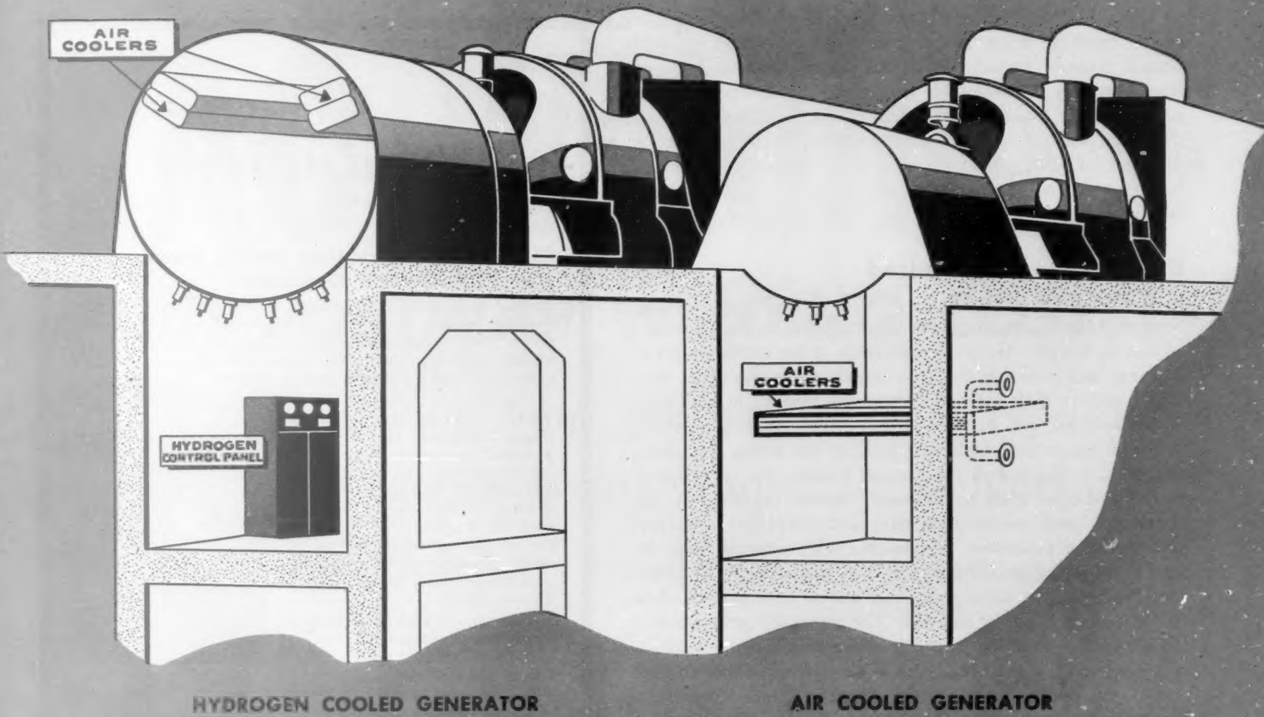
The delay in adapting the newer cooling medium to the smaller turbo-generators was largely based on the fact that the cost of certain features required on units cooled by hydrogen is practically independent of the machine rating. Also, until operation of the hydrogen cooling on the larger units was proved practically trouble-free, unforeseen expenses had to be anticipated. Now, however, such possible additional expense no longer remains as a potential disadvantage.

Complete new 20,000 kva unit

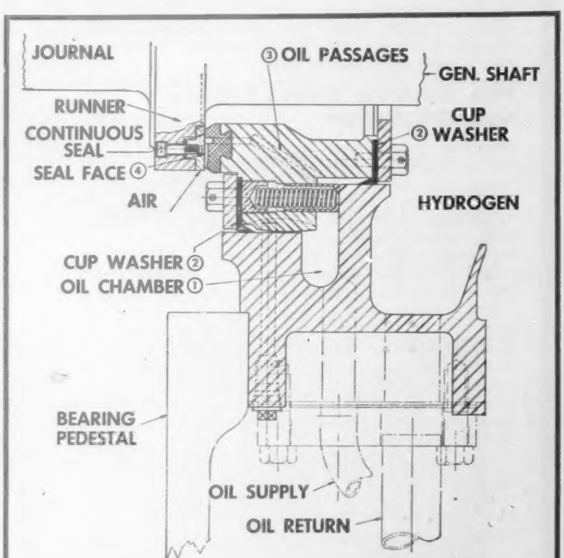
The newest development in hydrogen cooling is illustrated in the Ohio River Station of the Southern Indiana Gas and Electric Co. where the No. 4 and No. 5 generators have identical ratings and differ only in the cooling medium. Both generators are rated 20,000 kw, 25,000 kva, 80 percent power factor, 12,500 volt, 3 phase, 60 cycle, 3600 rpm. No. 4 is a standard air cooled machine installed in 1938 while No. 5, installed in 1944, is hydrogen cooled. Figure 1 is a power plant view of the No. 5 unit with No. 4 unit in the background.

The principal advantage of the No. 5 generator because of its hydrogen cooling is the reduction in windage loss. The windage loss in hydrogen is only 10 percent of the loss in air, and since this loss is constant, the saving in kilowatts is effective every hour the generator operates regardless of the load.

This apparent saving in power loss is somewhat modified by the addition of losses in the shaft seal, which, of course, are practically nonexistent in air cooled machines. However, the net reduction of losses because of the use of hydrogen result in monthly savings on this 20,000 kw unit equivalent to the power used by 1600 average residential consumers.



HYDROGEN AND AIR COOLING DESIGN are compared in basic outline here. Coolers in the generator frame increase above-the-floor size of the hydrogen-cooled unit somewhat, but additional space and duct work must be provided below the floor to house cooler in air-cooled unit.



SPECIAL SHAFT SEAL is one of the most important construction features of hydrogen cooling design. Pressure is maintained in the oil chamber (1), sealed by cup washers (2); oil flows through oil passage (3) to the seal face (4). Only hydrogen lost is carried away in the oil. (FIG. 2).

CONTROL PANEL for the hydrogen-cooled unit indicates hydrogen purity, pressure in the generator and oil pressure in the bearings and seals. Tanks next to the panel contain hydrogen and are connected to the generator to maintain positive pressure at all times. (FIG. 3).

Other and less tangible advantages enjoyed by generator No. 5 resulting from operating in hydrogen under one-half pound pressure include quietness of operation and longer insulation life. Considerable lengthening of insulation life is anticipated as the result of operation in an oxygen-free atmosphere with sufficient internal pressure to prevent the infiltration of dirt. Also in case of a winding failure the hydrogen in the machine will not support combustion and additional winding damage by fire is prevented.

Design changes required

In order that the generator be suitable for hydrogen cooling, certain changes and additions are required in the standard air-cooled design. The most noticeable is the explosion-proof housing, and probably the most important is the shaft seal. The generator shaft extends through the housing at both ends of the machine, and because of this construction oil seals are provided to prevent hydrogen leaking out along the shaft. (Figure 2.) Equipment for vacuum treating the oil supplied to the hydrogen seals is noticeably absent, resulting in less installation and maintenance time and simplified apparatus and operating procedure. Experience with a special seal, designed for minimum oil flow and, hence, negligible air influx into the hydrogen atmosphere, has shown very low oil flow to the hydrogen side of the seal. The air-cooled generator has the air coolers installed in the foundation below the machine requiring additional space and duct work, while the hydrogen-cooled unit has the coolers in the generator frame. Hydrogen atmosphere is confined under pressure inside an explosion-proof plate steel wrapper.

A special control panel (Figure 3) enables the operator to know the condition of the hydrogen cooling system at all times. Instruments on the front of the panel indicate hydrogen purity, hydrogen pressure, shaft seal oil pressure, bearing oil pressure and the operation of alarm relays. The various valves, relays and switches required for hydrogen control are located inside the cabinet.

Hydrogen increases output

The cost of additional equipment required by the hydrogen-cooled machine is partly compensated for by the additional output made possible by the hydrogen cooling. The thermal conductivity and heat transfer coefficients of hydrogen are such that from 15 percent to 20 percent greater output can be realized from the same active material. Since generators 4 and 5 have the same rating, No. 5 generator is approximately 18 percent shorter than No. 4. The reduction in size may not be apparent in the external appearance of the generator, however, because of the changes required in the machine frame to accommodate the air coolers.

When the machine is to be filled with hydrogen, the air is forced out with carbon dioxide before any hydrogen is admitted, thereby preventing any explosive mixture from forming in the machine. When hydrogen is to be taken out of the generator, the process is reversed.

Once the generator is filled with hydrogen the unit requires no more attention than an air-cooled machine. Hydrogen purity above 95 percent is maintained automatically in the generator during normal operation, and as a purity of less than 75 per cent is required for an explosive mixture, chances for an explosion are eliminated.

New Equipment

Disconnect Switch Uses Spring Pressure; Has High Current Capacity

Unique principle of a recently announced high current-carrying capacity, indoor disconnect switch has wide application in mills, industrial plants, utilities, and for switchboard builders—in any installation where parts of heavy current capacity a-c and d-c circuits must be isolated.

High contact pressure in the closed position and maximum ease of operating even the largest multi-pole assemblies are provided by a mechanism which releases spring pressure on contact surfaces during opening and closing of the switch. Contact pressure is applied by means of pre-set spring washers instead of screw threads (which ordinarily decrease contact pressure as they become worn).

Pressure on each stud contact is individually adjustable, so that each parallel blade member carries its share of the total current, and visible compression of the spring washers indicates the actual existence of contact pressure.

Switch blades can be locked at any angle in the open position by tripping a special latch which permits clamping hinge contacts under full spring measure. A positive "blow-out" proof latch to prevent opening of the switch by the action of short circuit forces is provided with the blades, and a second latch, on operating handle or hook-stick eye, prevents release of contact pressure by vibration.

Hand or hook-stick operated, the new type MC disconnect switch is available in sizes from 4000 to 10,000 amperes at 750 volts d-c maximum, and has a range of 3000 to 6000 amperes in a-c applications. Ratings of 3000, 4000, or 6000 volts, hook-stick operated, with high strength insulators may also be supplied. Complete details are available in Bulletin B6418.

New Electrode Holder Reduces Operator Fatigue

One-third lighter than corresponding size clamp type holders to decrease fatigue, a new screw-type electrode holder is now available.

Excellent balance and the fact that an electrode can be placed within the holder's jaw at *two* different angles contribute to maximum operating comfort.

The streamlined screw-type design assures firm electrode grip—one-half turn of the wrist releases electrodes. Exposed metal surfaces of the holder are constructed of spatter-resistant Mallory metal. Heat treatment of the electrode contactor prevents "electrode freezing" and wear on the shaft. The simple construction facilitates parts replacement, providing for long welding life. Heavy insulation assures cooler operation.

Available in light and heavy duty sizes to accommodate electrodes up to 3/8 inches in diameter, the light duty holder is 10½ inches long and weighs 17 ounces, while the heavy duty holder is 11½ inches long and weighs 19 ounces. Complete details are given in Bulletin M6407.

MORE FACTS about these new products are available on request. Write the Allis-Chalmers ELECTRICAL REVIEW, Allis-Chalmers, Milwaukee 1, Wisconsin.

"So They Dumped an 1800 lb. Compressor in Our Lap!"

"It's Yours, Old Man," said the Sullivan Machinery Co. to the Allis-Chalmers engineer. "All that compressor needs to make it happy is a motor. But it's got to have the right qualifications before it can keep company with my machine!"

"I Don't Want This! Looks like the motors in San Francisco and the compressor's in New York. What I want is a motor that'll hug that compressor so close you can't tell where one starts and the other ends. It's got to . . ."

Well, That Compressor Manufacturer made our heads whirl. Lighter . . . more compact . . . simple design . . . rugged construction . . . trouble-free . . . these were only part of what he wanted. So we measured and figured and made designs . . .

We Cut Overall Size by pressing the rotor on the compressor shaft. That eliminated motor bearings and with it lubrication worries and any chance of misalignment. A new type of housing reduced weight, helped pack more hp into less space.

Result: A completely integrated package unit with a mighty saving in space. To install it you only had to connect the leads and it began to purr. Speaking of purring — you should have heard Mr. Compressor Builder when he saw the finished product.

A 1926

There's a Moral: Every time Allis-Chalmers engineering solves *special* motor problems, we discover new ways to build better standard motors for you. Watch for these new and better motors from A-C.

Wait 'til you see the NEW

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